AD-A118 261

RADC-TR-82-87
Final Technical Report
May 1982

STRESS SCREENING OF ELECTRONIC HARDWARE

Hughes Aircraft Company

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER RADC-TR-82-87 / 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STRESS SCREENING OF ELECTRONIC HARDWARE	5. TYPE OF REPORT & PERIOD COVERED Final Technical Report August 80 - September 81
	6. PERFORMING ORG. REPORT NUMBER FR82-16-132
7. AUTHOR(s) A.E. Saari, S.J. VanDenBerg, R.E. Schafer	8. CONTRACT OR GRANT NUMBER(s) F30602-80-C-0250
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hughes Aircraft Company Ground Systems Group, P.O. Box 3310 Fullerton CA 92634	10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS 62702F 23380242
11. CONTROLLING OFFICE NAME AND ADDRESS Rome Air Development Center (RBET) Griffiss AFB NY 13441	12. REPORT DATE May 1982
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Same	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer: Eugene Fiorentino

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Screening
Stress Screening
Environmental Stress Screening
Stress Screening Model

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a study to develop quantitative and qualitative techniques for planning, monitoring and evaluating stress screening programs during electronic equipment development and production. A screening and debugging optimization (SDO) model developed on a prior study, RADC-TR-78-55, was revised to include current thermal cycling and vibration screening experience and an adaptive feature was added to allow stress screening program changes based on screening results. Guidelines

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EVALUATION

1. The objective of this study was to develop methodologies and techniques for planning, monitoring and evaluating stress screening programs during electronic equipment development and production.

2. The study objectives have been successfully achieved. Both qualitative and quantitative guidelines have been developed for tailoring screening procedures to specific hardware development and production programs. A methodology for screen selection and placement and for monitoring the screening process through use of adaptive procedures has also been developed. In addition, a previously developed stress screening model has been simplified and updated to include more recent stress screening experience. The model establishes a quantitative basis for planning and control. All of the major variables and inputs required for planning and evaluating screening programs are addressed through use of the model. Application of the techniques should greatly enhance the stress screening practitioner's capability to plan and conduct screening programs in a cost-effective manner.

3. Use of the techniques and methodology contained in the report should hopefully foster the development of a broader data base for estimation of model parameters and input variables. Users are encouraged to provide feedback of information on their application experience and results.

EUGENE FIORENTINO
Project Engineer

FOREWORD

This study was conducted to develop quantitative and qualitative techniques for planning, monitoring and evaluating stress screening programs. The effort included investigation of technical and economic factors leading to the adoption of a screening program and identifying factors which influence the selection of particular screens and placement of screens at various assembly levels.

A product of this study effort is a set of three computer programs (comprising the Stress Screening Model) which are intended to aid the stress screening practitioner in selecting screens, setting screening parameters and adjusting screens on the basis of observed results. The function of the Stress Screening Model (SSM) is to exercise some mathematical routines designed to find an optimum set of screens to achieve the desired, (user-input) results, subject to the user-indicated constraints.

If the quantity and type of latent defects present in equipment during each level of manufacture were known and the ability of the various stress screens to precipitate those defects into hard, detectable failures was also known, the planning of stress screening programs would be greatly simplified. Actually, the nature and magnitude of defects present are unknown and changing with time; screening strengths are not well understood and appear to be hardware dependent. Much stress screening has been done in the past several years and general patterns are beginning to emerge. Screening appears to be cost-effective. Temperature cycling and random vibration are commonly used screens and appear to be effective screens. Temperature cycle screening effectiveness appears to increase with wider temperature range and greater rates of change. Random, or broadband, vibration appears more effective than single or swept frequency vibration. Constant temperature burn-in, power cycling, and low level single frequency vibration screens do not appear to be generally effective. These patterns form an industry consensus on stress screening effectiveness.

The Martin-Marietta temperature cycling curves (Ref. 7) and the Grumman vibration curves (Ref. 8) are combined into NAVMAT P-9492 and are generally representative of the industry consensus. Screening strength equations developed previously by Hughes were modified to reflect the Martin/Grumman data and further adjusted to satisfy other stress screening results. The screening strength equations should not be interpreted as scientifically derived equations of general applicability but rather as useful tools to serve as a quantitative basis for planning and controlling a stress screening program. Use of the stress screening equations in conjunction with the screen selection and placement guidelines will provide a sound planning basis.

Careful review of stress screening results will enable the proper adjustment of the screening strength equations to match the items being screened through use of the SSM adaptive feature.

The SSM is easy to use but this should not be interpreted as meaning that planning, monitoring and evaluating a stress screening program is simple. Rather, it is the intent of the authors to provide a model which accepts all the major variables as user inputs, when available, but which can be meaningfully used when some input data is not available. The SSM contains default values for all but two user inputs and while considerable data gathering and analysis was necessary to establish the default values, they must be considered applicable only to the source from which they were derived. Each user should establish his own set of input variables applicable to his production processes and hardware item characteristics to make best use of the SSM and to have the most confidence in the results.

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1. INTRODUCTION AND SUMMARY.

1.1 Introduction. The use of environmental stress screening of electronic hardware during development and production has increased significantly in the past few years among many military electronic equipment manufacturers. The basic intent of stress screening is to detect latent defects, by subjecting test items to specific conditions of environmental stress, so that such defects can be degraded to a detectable level. "Latent defects", as used here, represent weaknesses in parts, workmanship and to some extent design, which result in much higher failure rates than what may be indicated by predicted inherent failure rate values. Electronic equipment delivered to the field often contain latent defects traceable to the production process. Such defects result in abnormally high failure rates and excessive repair costs in the field. Early stress screening of modules and assemblies, during production, is a widely accepted, effective means of alleviating the problem. Screening programs may be, however, costly to perform and may not be fully effective, perhaps even detrimental, if improperly applied and controlled. The technology base, in addition, for screening test selection, effectiveness measurement, and cost control, is largely under developed.

Stress screening programs should be designed to precipitate and detect latent defects early in the production cycle when it is most cost-effective to do so. Early stress screening can increase the likelihood of the completed equipment passing final acceptance and reliability demonstration tests and may eliminate or reduce the need for costly burn-in or reliability growth programs at the system level. Early life stress screening of modules and subassemblies, therefore, can offer a cost-effective means of enhancing equipment reliability and reducing production and field support costs.

Due to the varied nature of military electronics equipment and their associated design, development and production program elements, it is difficult to "standardize" on a particular screening approach. A tailoring of the screening process to the unique elements of a given program is, therefore, required. Screening tests such as temperature cycling and random vibration appear to be the most effective tests. However, exposure levels, number of cycles, and test durations differ widely among users. Other, perhaps less costly, tests such as sinusoidal vibration, power cycled burn-in at ambient and temperature soak are also used, but, in general, their effectiveness is believed to be less than the former tests. Precise information of the effectiveness of the various available screening tests is not currently known. Screening tests therefore should be selected based upon estimates of cost and test effectiveness, early development program data and on equipment design, manufacturing, material and process variables, which at least, narrow consideration to the most cost-effective choices. The screening process then should be continuously monitored and test results analyzed so that changes in the process can be made, as required, to optimize the cost-effectiveness of the screening program.

A survey of the current literature has shown that although the use of stress screening is on the increase, there is little general guidance as to how to best plan, monitor and control a stress screening program. The Institute of Environmental Sciences (IES), a professional organization of engineers and scientists, currently has a national program underway to develop a guideline document for Environmental Stress Screening of Electronic Hardware. Results of this effort were published in a guidelines document (Ref. 12).

Hughes Aircraft Company is also preparing a Stress Screening Guidelines document for internal use which is expected to be released in 1982.

1.1.1 Objective and Scope of Study. The objective of this study was to develop quantitative and qualitative techniques for planning, monitoring and evaluating stress screening programs during electronic equipment development and production. The work effort investigated methodologies for test selection and control which provide assurance that reliability growth is achieved in a cost-effective manner throughout the development and production process. The work performed was concerned primarily with the cost-effectiveness of stress screening at levels of assembly above the part level, i.e., assembly/module, unit/group and equipment/system. Part level screening considerations were included in the study only to the extent that the quality grade of components used influences the initial quantity of latent defects and therefore the planning of the stress screening program.

1.2 Summary of Study

1.2.1 Study Approach. The basis of stress screening is the elimination of latent defects at a point in the production process when it is least costly to do so. Figure 1.1 depicts a typical production process where parts and printed circuit boards (PCB) or wired chassis comprise assemblies; then manufactured assemblies, purchased assemblies and associated wiring comprise units; and finally the units, other equipment and intercabling make up the completed system. Latent defects are introduced at each stage in the process and, if not eliminated, propagate through to field use. The cost of repair increases with increasing levels of assembly, being $1 to $5 at the part level and perhaps as high as $1000 at the system level. Field repair cost estimates have been quoted as high as $15,000. For economic reasons alone, it is desireable to eliminate latent defects at the lowest possible level of assembly and certainly prior to field use.

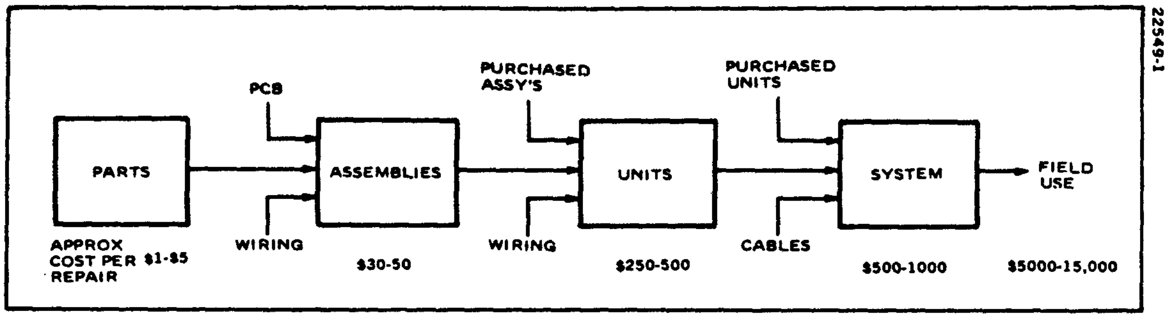

Figure 1.1. A Typical Production Process. Finding defects at the lowest level of manufacture is most cost effective.

Latent defects can be transformed into patent, or hard, defects through the application of environmental stresses such as elevated temperature operation, temperature cycling or vibration.

The probability that a stress screen will transform a latent defect into a hard failure (given that there is a latent defect present) and that failure will be detected by the screen is called "screening strength". Screening strength varies with the screen parameters, (e.g., the strength of a temperature cycle screen increases with increases in temperature extremes, temperature rate of change and number of cycles). But there is a cost associated with application of a stress screen and that cost varies with screening strength. There are then many possible combinations of screening strengths and screening costs at each level of assembly and the objective is to find the lowest cost set of screens that produces the desired results. A computer program is available to perform this "optimization" function and is discussed below.

1.2.2 <u>The SDO Model</u>. A prior study (Ref. 1) conducted by Hughes for RADC resulted in development of a Screening and Debugging Optimization (SDO) model which provides an optimum set of stress screens based on model inputs of estimated number of initial and process-induced defects and estimated screening costs. The model contains empirical screening strength equations for five stress screen types (constant temperature, constant power, cycled power, cycle temperature, and vibration) in which the screening strength is a function of screening parameters such as temperature extremes, number of cycles, rate of change of temperature, and screen duration. Since there are a very large number of combinations of stress screens and screen costs at each level of assembly, e.g., at assembly/module, unit/group, and equipment/system levels, the SDO model utilizes a dynamic programming algorithm to find the optimum solution to either,

1) the set of screens which achieve a predetermined reduction of latent defects for the least cost, or

2) the set of screens which achieve the maximum reduction of latent defects for a fixed cost.

The SDO model was retained for this study because of its optimization capability. However, many changes were made to the model during the course of this study, as indicated below.

Previous SDO Model	Model Changes
1) Screening strength equations do not reflect recent stress screening experience.	More current equations were substituted for existing equations.
2) Vibration screening strength equation is only for single frequency vibration.	Equations were added for random vibration and swept-sine vibration. A new equation for single frequency vibration was substituted.
3) Model is difficult to use. Many user inputs are required.	Use of the model was simplified by: a. Minimizing user input requirements. b. Providing clear instructions for model use. c. Providing examples to aid the user. d. Making the model interactive for use on time-share terminals. e. Including user prompter and assist instructions. f. Output formats were improved to facilitate user understanding.
4) The solution of the optimum set of screens	The dynamic programming algorithm was altered to a

determined by the model was, occassionally, unrealistic (e.g. 5 different screens might be required sequentially at the same level of assembly).	contrained optimization solution to provide an optimum set of screens consistent with current practice.
5) Running of the model can be costly (much core is required and CPU time can become significant for large systems).	Unnecessary precision was eliminated. Instructions were reduced.
6) SDO model does not have "adaptive screening" capability.	Adaptive feature was added to allow an adjustment of stress screen parameters on the basis of results observed. Screening strength and initial fraction defective estimates can be derived from observed results using the chance-defective exponential (CDE) model.

1.2.3 Screening Strength Equations. Screening strength equations were developed for random vibration, swept-sine vibration, single frequency vibration, temperature cycling, and constant temperature. The first three equations (those for vibration) were developed from the results of the vibration screening experiments conducted by Kube and Hirschberger (Ref. 8). Experiments conducted by Edgerton (Ref. 5) and Baker (Ref. 6) did not produce sufficient vibration induced latent defect precipitation to enable model development. No other controlled experiments with the effectiveness of vibration were identified by the literature search. The development of the vibration screening strength equations is described in detail in Appendix A. Figures 1.2, 1.3, and 1.4 show screening strength versus time for the three vibration types.

The temperature cycling screening strength equation is derived from the curves on page 6 of NAVMAT P-9492 (Ref. 9). It was assumed that the curves represented results primarily from AGREE testing of avionics equipment and represent -54 deg. C to +55 deg. C temperature extremes and a 5 deg. C/minute rate of change. The constant temperature screening strength equation is derived from the temperature cycling equation. Figures 1.5 and 1.6 show screening strengths for the temperature related equations. The derivation is described in Appendix A.

1.2.4 Adaptive Screening. Since the stress screening equations are empirically derived, they are only rough quantitative

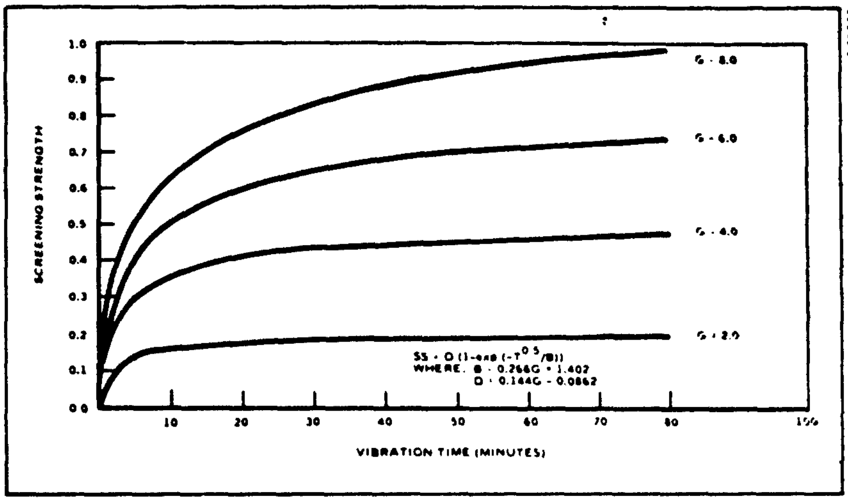

Figure 1.2. Screening Strength for a Random Vibration Screen

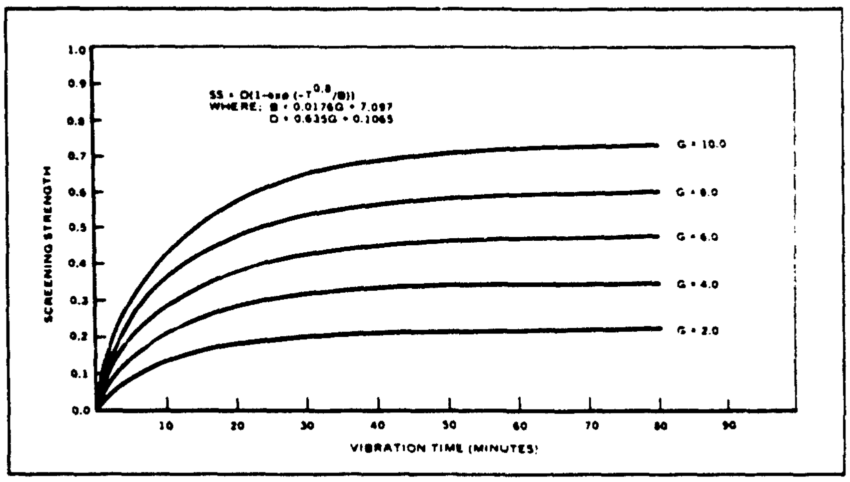

Figure 1.3. Screening Strength for a Swept-Sine Vibration Screen

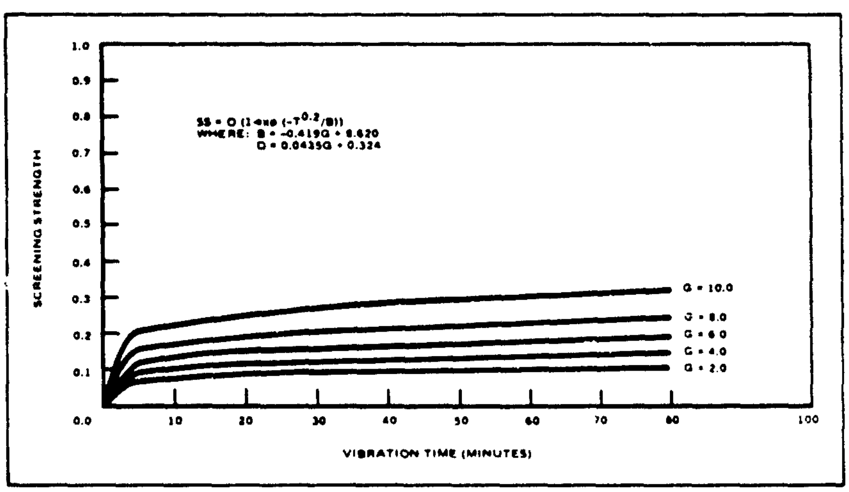

Figure 1.4. Screening Strength for a Single (Fixed) Frequency Vibration Screen

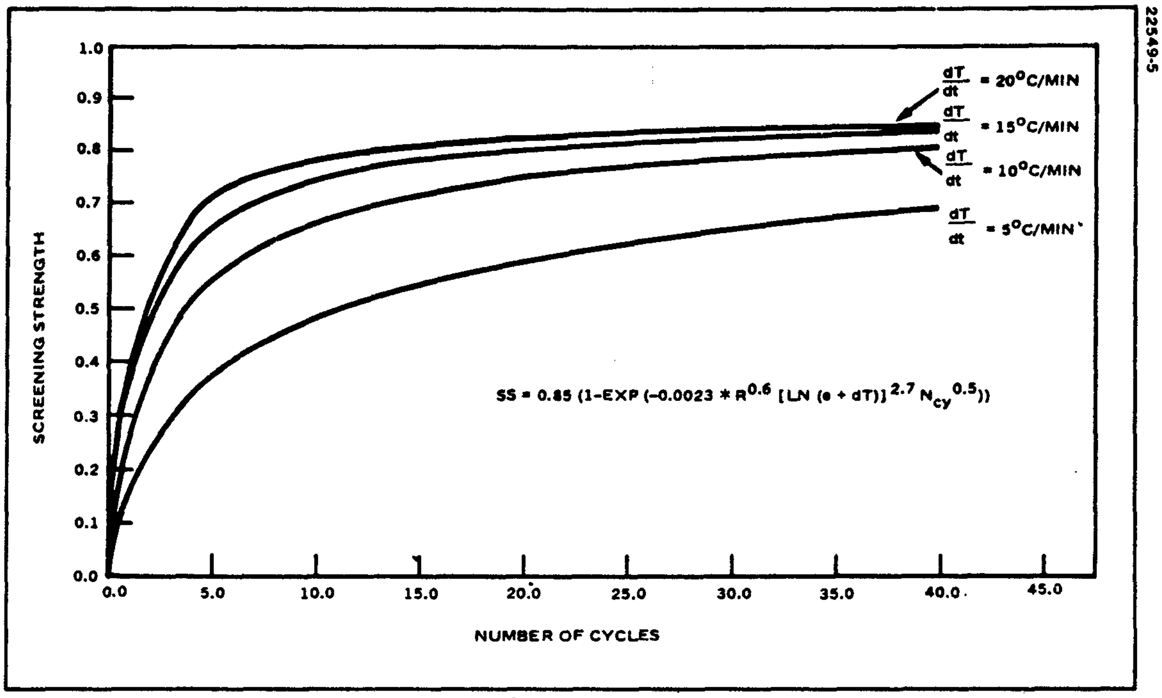

Figure 1.5. Screening Strength for a Temperature Cycling Screen (R = 100)

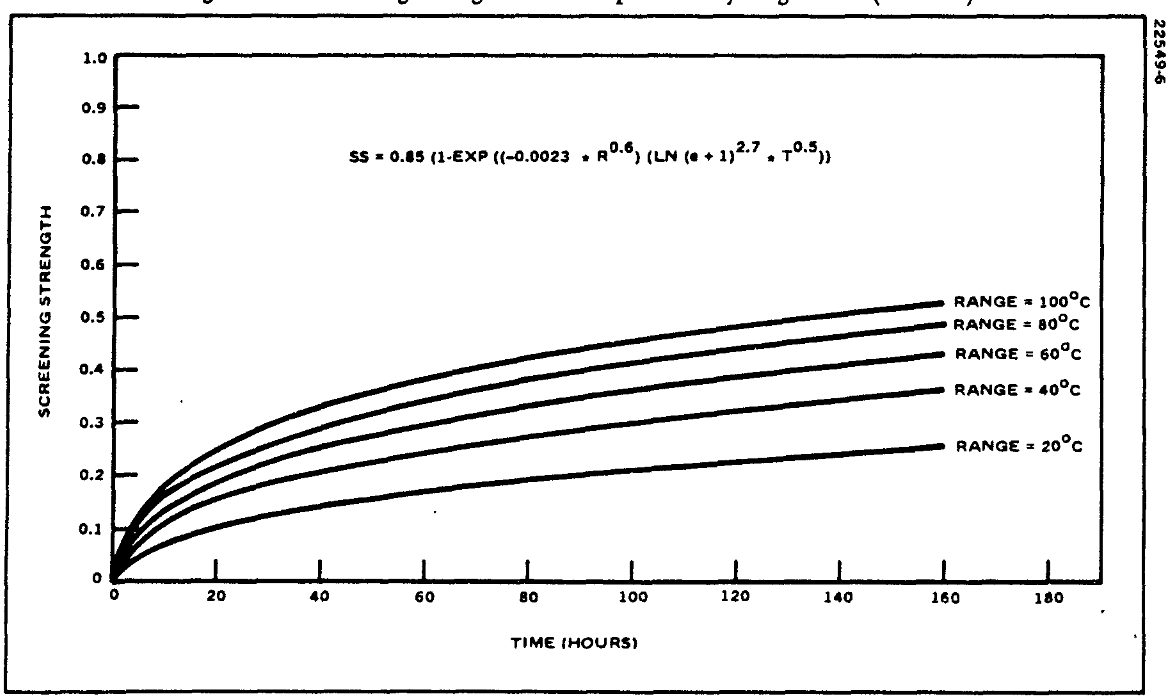

Figure 1.6. Screening Strength for a Constant Temperature Screen

approximations of the screens' ability to precipitate latent defects. Screening strength is also thought to depend on other factors such as equipment type, construction, size, part composition and degree of design and production maturity. Therefore, the equations are useful in establishing a starting point and serve as a basis for planning a screening program. As actual screening results become available they can be compared with the expected results as determined by the screening strength equations. If the actual results fall outside the 99 percent bounds on the expected results, the actual data can be entered into the model which will automatically adjust the "equipment-related" constants of the stress screening equations, thereby adapting the equations to the specific hardware characteristics. The 99 percent bounds are based on a statistical test of the hypothesis that the planned values are correct (with a probability of 1 - .99 = .01 of rejecting the hypothesis when it is true).

1.3 Summary of Industry Surveys

1.3.1 Surveys Previously Conducted and Reviewed for this Study. Three surveys previously conducted on the subject of stress screening were reviewed and the results of each are summarized in the following paragraphs.

The results of the three surveys show marked similarity because there are common respondents to the surveys reporting on the same experiences. Much of the experience data reported shows striking similarity in stress screens used, screening parameters (e.g., temperature extremes, temperature rates of change, vibration levels) and in opinions as to which screens are most effective. This is attributed to the fact that much of the reported screening experience is the result of contractually required MIL-STD-781B AGREE testing, primarily on avionics "black boxes".

1.3.2 Martin-Marietta Survey (Ref. 7). This survey of twenty-six sources primarily reporting on AGREE testing experience indicate the following beliefs.

NOTE: This survey represents experience and opinions of about ten years ago and a large amount of stress screening experience, apart from AGREE testing, has been accumulated since then.

a. 6-10 thermal cycles are required for the elimination of incipient defects. As more complex the screened item becomes (i.e., by part count), more cycles are required.

b. More than 10 cycles are required if screening is done at the assembly level, and unscreened parts are used. 16-25 cycles have been used.

c. A temperature range of -54 deg. C to 55 deg. C is most commonly used. (AGREE temperature range for avionics). Best screening is provided by using the maximum safe temperature range and rate of change.

d. Temperature cycling of soundly designed hardware does not degrade the hardware.

e. Application of power during temperature cycling with continuous performance monitoring is recommended. Turning off power during the cool-down cycle allows a more rapid temperature rate of change and allows parts to reach the low temperature extreme.

f. Failure-free cycles are sometimes used. The report recommends one failure-free cycle.

g. Implementing temperature cycling is most compatible with printed circuit board (PCB) construction and least compatible with large, complex potted cordwood modules.

h. Augmenting "black box" temperature cycling with additional cycling at the PCB level should be considered.

i. An approximation of the types of failures detected in mature hardware by temperature cycling is:

Design-related	5%
Manufacturing-related	33%
Part-related	62%

j. Temperature cycling is an effective screen, with the screening strength dependent on the temperature range, temperature rate of change and number of cycles. Temperature soaks and low-level vibration are not effective screens.

1.3.3 McDonnell Aircraft Company Survey (Ref. 11). This survey was conducted during 1979-1980 of thirty-three avionic equipment manufacturers to determine the industry practice and opinions current at that time in the conduct of environmental screening. A summary of the survey results follows.

a. The primary environmental stress screen used is a thermal cycle, with a high temperature limit of 55 deg. C or 71 deg. C most common and a low temperature limit of -55 deg. C most common, reflecting the test limits of MIL-STD-781B.

b. Temperature cycle durations of six to eight hours are most common and probably reflect convenience in adapting to the 24-hour day rather than for screening effectiveness purposes.

c. Four to ten temperature cycles is most common, with the last cycle being failure free.

d. The most common temperature rate of change is 3 to 5 deg. C/minute.

e. Vibration during temperature cycling was limited to MIL-STD-781B requirements (i.e., 2.2g, sinusoidal, 10 minutes/hour). Some random vibration was used as a screen, separate from the temperature cycling, using levels of 3 to 6.2g RMS for durations of 5 to 10 minutes in 2 or 3 axes.

f. There was no concensus on when random vibration should be done when applied with temperature cycling (i.e., before, after, or in-between temperature cycling).

g. The distribution of the types of failures detected as a result of temperature cycling is:

Design-related	8%
Manufacturing-related	30%
Part-related	46%
Other	15%

The above percentages are mean values with large variances, reflecting varying degrees of production maturity. Soldering defects were the most common manufacturing related defect.

h. Factors influencing the design of a screen for a new production item were:

Factor	Percent of Respondents
1) Previous experience on similar equipment	91
2) Customer desires	67
3) Equipment characteristics	67
4) Reliability requirements	64
5) Use environment	58
6) Existing environmental facilities	48
7) Test operating cost	36

i. About 40% of the respondents reported that the screen had been changed after the start of production and the majority (80%) of the changes were to increase the screen (more temperature cycles, added burn-in, added random vibration, increased vibration level) as a result of poor reliability resulting from the initial screen.

1.3.4 Institute of Environmental Sciences (IES) Survey (Ref. 12). This survey was conducted during 1980-1981 by an IES-sponsored National Committee to develop an environmental stress screening guidelines document. The survey resulted in receipt of 85 detailed responses from 14 sources and over 50% of the responses were for avionics applications. Salient findings of the survey are as follows:

a. Thermal cycling and vibration were the most common stress screening environments used at the module, unit and system levels. Survey respondents also believe that thermal cycling and vibration are the most effective stress screens.

b. Equipment reliability can be improved by 25 to 90% by means of environmental stress screening. The range of reliability improvement varied widely depending on equipment type, screening environment and the levels of assembly at which screening was performed.

c. Thermal cycling was found to be a more effective screening environment for electronics than vibration, by a factor of 3 or 4 to 1. Random vibration is more effective than swept sine, and swept sine is more effective than fixed sine.

d. Both thermal cycling and vibration are needed for optimum screening effectiveness. It is inconclusive that it is more effective to perform thermal cycling or vibration in any specific sequence but there appears to be a synergistic effect of using both the environments.

e. Module-level temperature cycling is generally 20 to 40 thermal cycles, with a temperature rate of change of 5 deg. C/minute most common, and no power applied to the module. There is no significant payoff to extend the number of cycles beyond 40. Increasing the temperature rate of change produces more effective screening. Application of power to the module during the screen does not increase screening effectiveness.

f. Units and system level screening profiles used reflect the strong influence of MIL-STD-781B in temperature range and rate of change. 8 to 12 thermal cycles, with power applied, were most common.

g. Some cases were noted where degradation was introduced in equipment at high levels (i.e., 6gRMS) of random vibration. There is also an indication that lower levels of random vibration can be as effective as higher levels in some applications.

1.3.5 Survey Consensus. Thermal cycling and vibration are thought to be the effective environmental stress screens for precipitating latent defects. A large part of the reported stress screening experience data is a result of contractually required AGREE tests in accordance with MIL-STD-781B, test levels E and F, for avionics equipment. The AGREE requirements have obviously strongly influenced the survey respondents with regard to temperature cycling and vibration. This, at least partly, explains the commonality in stress screening practice. Most screening experience is at the unit, or "black box", level and a range of 4 to 12 thermal cycles is believed to be sufficient to screen out latent defects. There is some belief that the more complex the unit (i.e., in part count), more thermal cycles are needed, although this belief is not universally accepted. The most common temperature range over which thermal cycling is done is -54 deg. C to +55 deg. C, again reflecting the influence of MIL-STD-781B. There is a common belief that greater temperature ranges provide more effective screening, provided that the temperature limits are within the safe operating limits of the unit being screened. The most common temperature rate of change appears to be 5 deg. C/minute and there is general agreement that higher rates of change provide more effective screening. Temperature cycling at the unit level is most often accomplished with power applied and close monitoring of performance at both temperature extremes is recommended. Power is turned off during the cool down cycle. Application of power during temperature cycling at the module level does not appear to increase the effectiveness of unpowered screening. There does not appear to be a clear consensus on the use of failure-free cycles. While the practice of requiring the last cycle to be failure-free is used by some and supported by others, there is another group who believe that a failure-free requirement should be included with other acceptance criteria and kept separate from the stress screening process.

Random vibration is considered to be the most effective vibration screening process, followed by swept frequency sinusoidal vibration (swept sine) and fixed frequency sinusoidal vibration (fixed sine).

Fixed sine vibration at low levels (e.g., 2.2g) is almost universally believed to ineffective as a workmanship screen. Random vibration at levels of 3-6gRMS, for 5-10 minutes (per axis), and applying to 2 or 3 axes is currently thought to be the most effective screen. However, the application of random vibration is relatively new and the survey results were mostly reports of AGREE testing, using 2.2g fixed sine vibration. Vibration at the module level is not currently thought to be effective.

Screens other than temperature cycling and vibration (e.g., temperature soak, power ON-OFF cycling) are not considered to be effective screens. Combining screens, such as performing temperature cycling and vibration on the same unit simultaneously or sequentially is considered to be effective. Opinions are mixed, however, on whether simultaneous screening is more effective or has the same effectiveness as sequential screening. There is also no agreement on the most effective sequence of combined screens, i.e., vibrate before or after temperature cycle.

Table 1.1 summarizes the key issues of the three surveys.

TABLE 1.1 SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Aircraft Company Survey (Ref. 11)	IES Survey (Ref. 12)
Thermal Cycle Screening	6-10 cycles. More cycles are required for more complex units & when done at lower assembly levels.	4 and 10 cycles most common. No. of cycles used varies widely (2 to 70 cycles).	8-12 cycles, independent of unit part count. 20-40 cycles for module level temp. cycling.
Temperature Range	$-54^{\circ}C$ to $+55^{\circ}C$ most common. (influence of AGREE testing.) Maximum safe range is most effective.	$-54^{\circ}C$ to $+55^{\circ}C$ or $+71^{\circ}C$ (influence of AGREE testing)	Not stated, but stress screening cycles strongly influenced by AGREE testing profiles.
Temperature Rate of Change	$1^{\circ}F$ to $40^{\circ}F$/min. with higher rates more effective.	$3^{\circ}C$ to $5^{\circ}C$/min.	$5^{\circ}C$/minute. Higher rates (15-20 C/min.) at module level more effective.
Power ON vs. OFF	ON, with close monitoring of performance. OFF during cool-down portion.	Not stated, but expected to follow AGREE profile. (ON, except during cool-down portion.	ON, for Unit and System-Level. Functional testing at both extremes. OFF, for module-level.

TABLE 1.1 SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Aircraft Company Survey (Ref. 11)	IES Survey (Ref. 12)
Failure-Free Cycles	0-2 cycles FF. 1 FF cycle recommended.	Varies greatly, 0 to 22 FF cycles 1 FF cycles is most common.	Should be made part of acceptance criteria, separate from stress screening.
Random Vibration	Not addressed	3-6.2gRMS, 5-10 minutes per axis, 2 or 3 axes.	Various Levels. Many are using NAVMAT P-9492, 6gRMS. Recommends tailoring to item being screened. Not effective at module-level.
Degradation	Temperature cycling does not degrade soundly designed hardware.	Not addressed.	Cases noted where high levels of random vibration (6g RMS) cause degradation.

TABLE 1.1 SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Aircraft Company Survey (Ref. 11)	IES Survey (Ref. 12)
Distribution of Defects:			
Part-related	62%	46%	Not addressed
Manufacturing-related	33%	30%	
Design-related	5%	8%	
Other	-	15%	
Effectiveness of screens other than temperature cycling and random vibration	Low Level (2g) Fixed Sine Vibration and temperature soak are not effective screens.	Low level (2g) Fixed Sine Vibration not effective. Opinion mixed on effectiveness of temperature soak	All screens other than temperature cycling and vibration are less effective substitutes.
Combined Temperature Cycling and Random Vibration	Not addressed, except that AGREE vibration is not an effective screen.	Majority think combining the screens is more effective than applying singly.	Combined testing is no more effective than applying screens singly. Using both temp. cycling and vibration singly is necessary and a synergistic effect is gained.

TABLE 1.1 SUMMARY OF THREE PREVIOUS SURVEYS.

Topic	Martin-Marietta Survey (Ref. 7)	McDonnell Aircraft Company Survey (Ref. 11)	IES Survey (Ref. 12)
Sequence of Temperature Cycling and Vibration, when used singly.	Not addressed.	Respondents indicated various combinations, vibration before, after and in-between temp. cycling, with no concensus opinion on which is most effective.	No preferred sequence. Applying either screen before and after the other screen shows additional fall-out.
Reliability Improvement through Stress Screening	Not specifically addressed, but there is general agreement that temp. cycling eliminates incipient defects (and it can be inferred that reliability will thereby improve)	Not specifically addressed, but there is general agreement that temp. cycling eliminates incipient defects (and it can be inferred that reliability will thereby improve)	Equipment reliability can be improved by 25-90% through stress screening.

2. PLANNING A STRESS SCREENING PROGRAM.

2.1 Introduction. The ultimate success of a stress screening program is strongly dependent on the care taken in planning and understanding the limitations of stress screening. The planning of a stress screening program involves a number of considerations which are addressed below. Two important considerations should be kept foremost in mind in the process of planning a stress screening program;

- The quantitative aspects of stress screening, i.e., the expected number of latent defects and the ability of a specific screen to precipitate those defects, cannot be analytically determined, and any models purporting to do so must be recognized as approximation methods based on past experience.

- Past experience may provide some guidance in stress screen selection in cases of similar equipment composition and construction and degree of production maturity. However, there are usually other factors involved (e.g., reliability improvement fixes may have been incorporated simultaneously with the start of stress screening) which may obscure the true source of improvement.

Other factors to consider are:

- What are the objectives of a stress screening program? (e.g., achieve a quantitative reliability goal, maximize reliability, reduce production costs, reduce warranty costs, minimize life cycle costs?)

- What are viable alternative stress screens for achieving objectives (which screens applied at which levels produce the desired results?)

- What are the costs associated with each of the alternative approaches? (consider both nonrecurring and recurring costs)

- How does one know if the screening program is going according to plan (data gathering, analysis, decision criteria)?

- How can a stress screening program be changed to achieve more cost effective screening?

- What are things that can go wrong, what early indications are there and what should be done to correct them?

- How to and why keep management attention on benefits being derived from stress screening?

2.2 Developing a Stress Screening Plan

2.2.1 Establishing an Objective. The most common objective in establishing a stress screening program is to improve field reliability by eliminating latent defects in the factory prior to delivery. This objective includes motivation through warranty considerations as well as motivation to improve poor field reliability. Other objectives to consider are:

a. Meeting a contractual reliability demonstration requirement.

b. Achieving and maintaining a high field reliability level.

c. Assuring cost effectiveness in a Reliability Improvement Warranty (RIW) contract.

d. Reducing production costs.

e. Reducing field costs of operations and maintenance (O&M)

The cost of failing a reliability demonstration is high enough to negate most compromises. The amount of screening planned should be consistent with the specified MTBF and test decision risks. The same approach should be considered on a reliability improvement warranty (RIW) contract. It should be noted that more screening is not always better and the improvement per unit of time decreases with time.

Achieving and maintaining a high field reliability requires careful evaluation of problems which could adversely affect reliability levels and an understanding of how such problems can be eliminated or controlled.

2.2.2 Determining if a Stress Screening Program is Appropriate. The current popularity of stress screening might lead one to believe that it is a panacea for solving problems of low field reliability, high production rework costs and slipping production schedules. Unfortunately, there are many other causes of such problems and no simple solution exists for correcting (or preventing) them. The value of stress screening, i.e., the knowledge of what potential technical or economic benefits are derivable from stress screening, should be understood before a decision is made to apply it. Generally, on high volume production programs of complex hardware the cost-effectiveness of stress screening should be considered. It is not so obvious that stress screening is cost-effective, or otherwise beneficial, on a single system, advanced development model, where the production phase is remote and the non-recurring costs for stress screening facilities and test equipment are not insignificant.

The construction and complexity of the development item are important considerations. A breadboard or brassboard model which has little resemblance to a future production model should not be screened for manufacturing/workmanship defects. A development model which is expected to undergo extensive productization changes falls in the same category. Pre-production models embodying new designs are prime candidates for stress screening in a development phase because the types of defects to be expected in production can be identified and a production stress screening program can be effectively planned.

To determine if a stress screening program is appropriate, consider the following:

- Does the reduced field maintenance cost justify the screening program cost?
- Is stress screening necessary for eliminating excessive latent defects?
- Is stress screening necessary to achieve a technical (e.g., reliability) requirement?
- Will stress screening (in a development phase) provide valuable information for planning the production stress screening program?
- Will stress screening save money in production (through reduced rework costs)?
- Is the improved production schedule resulting from stress screening worth the cost of screening?
- Does the goodwill derived from delivering latent defect-free products balance the cost of stress screening?

2.2.2.1 <u>Field Maintenance Cost Savings through Stress Screening</u>. Field maintenance costs resulting from latent defects can be calculated by multiplying the number of latent defects present by the average cost per field repair. Figure 2.1 is a simplified production flow process of an unscreened unit. Assume the unit has N=10,000 parts, of which p=.001 fraction defective, resulting in the introduction of 10 latent defective parts. Further, assume 20 workmanship defects are introduced at the assembly level and 10 more at the unit level. The normal assembly and unit operational testing is assumed to have screening strengths of

0.20 at the assembly level and 0.40 at the unit level. Then, only 6 latent defects are precipitated at the assembly level (0.20 x 30 defects) and 14 at the unit level. Since a total of 40 defects were introduced in the process and 20 were precipitated, a balance of 20 remain to fail in subsequent field use.

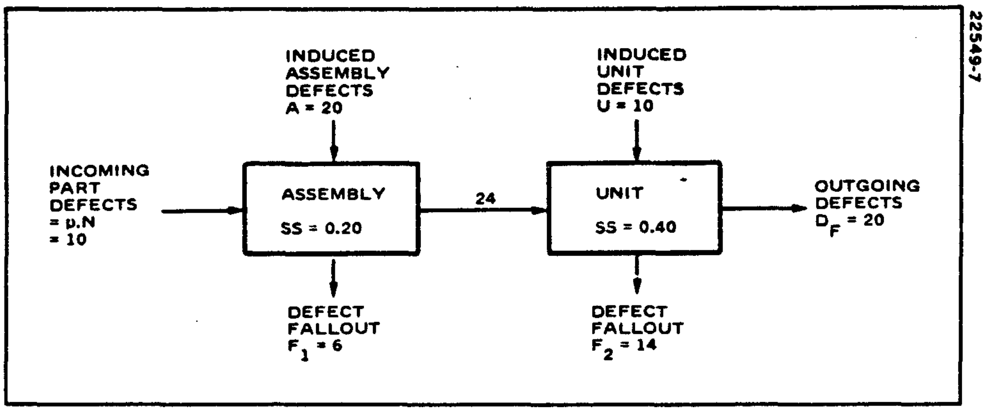

Figure 2.1. Latent Defect Flow for Process Without Stress Screening

Figure 2.2 shows the same unit with stress screening at both the assembly and unit levels and screening strengths of 0.70 are assumed. The same number of latent defects are introduced (40) but because of the increased screening strength, 34 defects are precipitated, leaving only 6 defects to be found in field use. The reduction of 20-6=14 defects saves $140,000 in maintenance costs (at $10,000 per repair). If the cost of doing the screening is less than the discounted value of $140,000, the screening has been cost-effective.

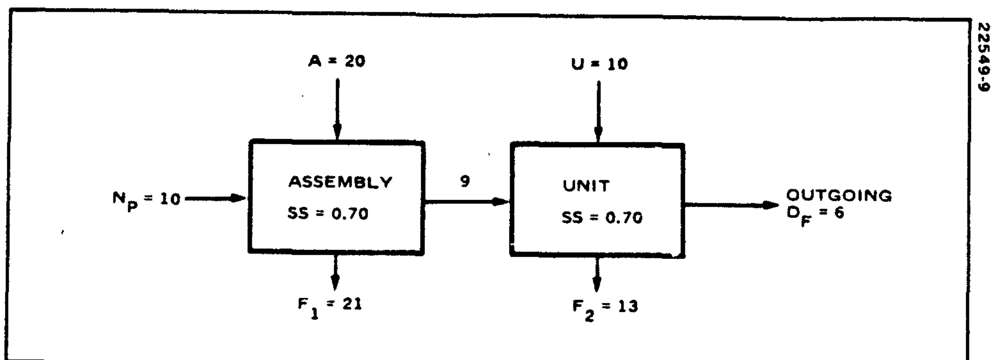

Figure 2.2. Latent Defect Flow for Process with Stress Screening

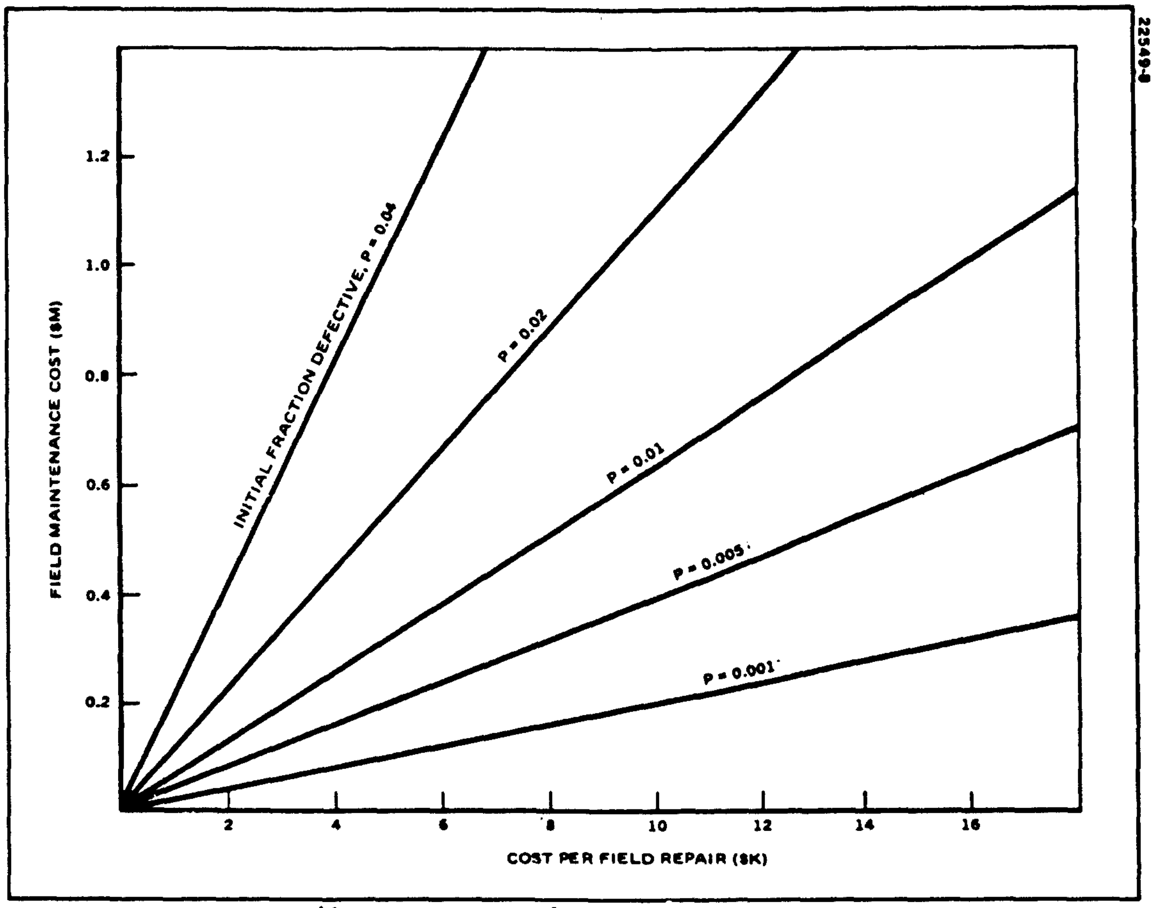

Figure 2.3. Field Maintenance Costs for Repairs Resulting From Latent Defects

Figure 2.3 shows that, for this example, at $10,000 per field repair a total of $200,000 will be spent in maintenance as a result of the 20 latent defects (p=.001). The figure shows costs rise rapidly as the initial fraction defective increases.

2.2.2.2 Using Stress Screening to Achieve a Reliability Requirement. It is generally believed that large part populations are comprised of two subpopulations, viz., "good" parts with a low failure rate, λg , and "bad" parts with a high failure rate, λb. It is further believed, and empirical and experimental evidence supports, that the good subpopulation dominates. The fraction of good parts in the population may be from 0.9 to 0.999, depending on the part type and quality grade. There is increasing evidence (ref. 19) that failures occurring during the life of equipment are latent defectives precipitated to hard failures through the application of the normal field usage stresses over a period of time. The continuously decreasing subpopulation of bad (latent defective) parts results in an equipment life characteristic of a decreasing failure rate.

If the expected instantaneous failure rate of an equipment is the summation of the failure rates of the good and bad (defective) parts,

$$\lambda_{\text{equipment}} = (N-D)\lambda g + Dk\lambda g \qquad (2\text{-}1)$$

where, N = total part population

D = number of defective parts

λg = good part failure rate

$k\lambda g$ = defective part failure rate

and if estimates of λg and k can be made, then the number of latent defects that corresponds to a desired equipment failure rate can be determined by solving (2-1) for D,

$$D = \frac{\lambda_{\text{equipment}} - N\lambda g}{\lambda g(k-1)} \qquad (2\text{-}2)$$

Equation 2-2 addresses only latent defective parts and thereby excludes latent workmanship defects, which can be included by expanding equation 2-1,

$$\lambda_{\text{equipment}} = (N-D)\lambda_g + Dk_1\lambda_g + (M-C)\lambda_c + Ck_2\lambda_c \qquad (2\text{-}3)$$

where, M = total number of electrical connections

C = number of latent defective connections

λ_c = good connection failure rate

$k_2\lambda_c$ = defective connection failure rate 2

Equation 2-3 can be used in planning and monitoring a stress screening program for determining the necessary reduction in the initial number of defective parts and the number of latent defective connections that yield a value of λ equipment that corresponds to the desired equipment failure rate. At the conclusion of stress screening, there are still some residual latent defects. As these latent defects are precipitated by field use, the reliability will improve because the latent defects are replaced (with high probability) with good parts. See Appendix E for a theoretical discussion of long term field reliability improvement through latent defect elimination. Figures 2.4, 2.5 and 2.6 show this reliability improvement for systems of 2,000, 10,000, and 20,000 parts and initial fraction defective rates of .001, .005, and .01. The figures represent systems of three different part counts, and undergo a natural screening of latent defects (no stress screening) in which the good part failure rate is 10^{-7} and the bad part failure rate is 2×10^{-4}. The curves in Figures 2.4, 2.5, and 2.6 were derived from a simulation program which simulates failures of good and bad parts and keeps track of cummulative MTBF as the number of failures due to bad parts decreases with time.

2.2.2.3 Manufacturing Cost Savings through Stress Screening. Consider the production model shown in Figure 2.7. The figure shows a moderately large production operation involving 100,000 parts. This may represent a single, large system of that many parts or multiple systems whose total part count is 100,000. Assume that, without stress screening, the natural screening strengths of the assembly, unit and system levels are 0.2, 0.4 and 0.6, respectively. If the incoming part defect rate is 0.5 percent and induced workmanship defect rates (as a fraction of the number of parts) are as shown in the figure, a total of 850 latent defects are introduced into the process and 672 of them are precipitated, detected and removed in the process, with the balance of 178 remaining to be discovered in field use.

If stress screening is employed at the assembly and unit levels, each with screening strengths of 0.70, the resulting defect fallout at each level is as shown in Figure 2.8.

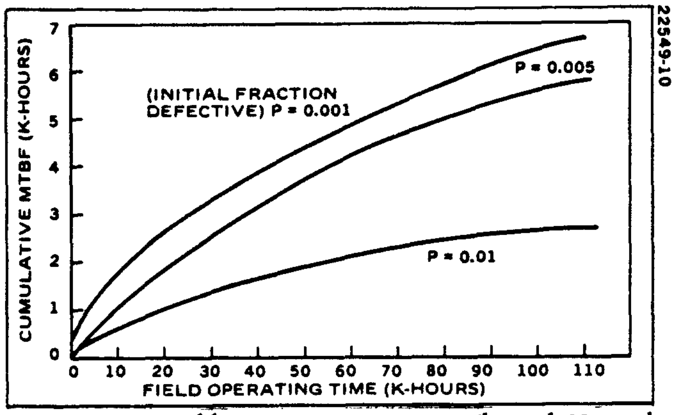

Figure 2.4. Field MTBF Improvement Through Natural Latent Defect Fallout (2000 Part System)

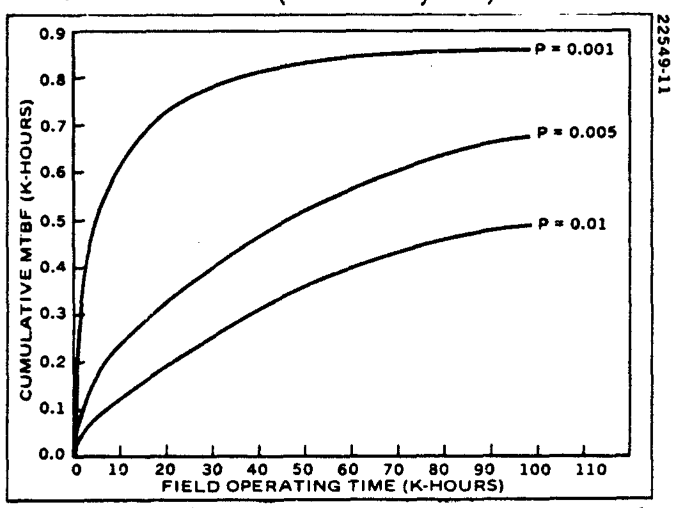

Figure 2.5. Field MTBF Improvement Through Natural Latent Defect Fallout (10,000 Part System)

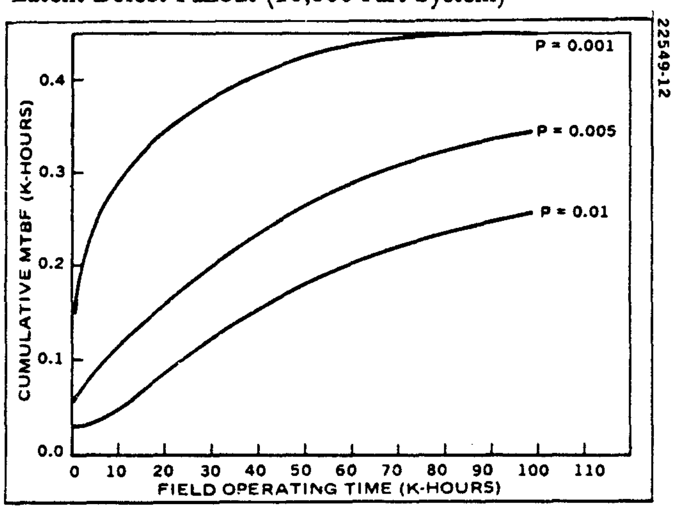

Figure 2.6. Field MTBF Improvement Through Natural Latend Defect Fallout (20,000 Part System)

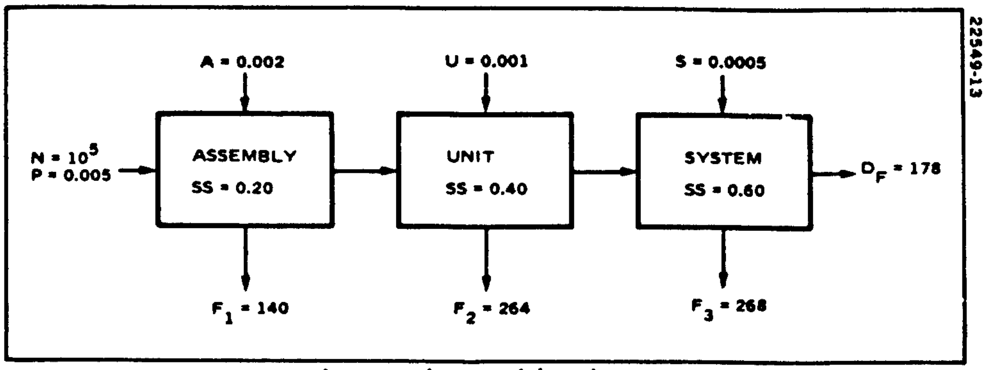

Figure 2.7. Production Flow Model Without Stress Screening

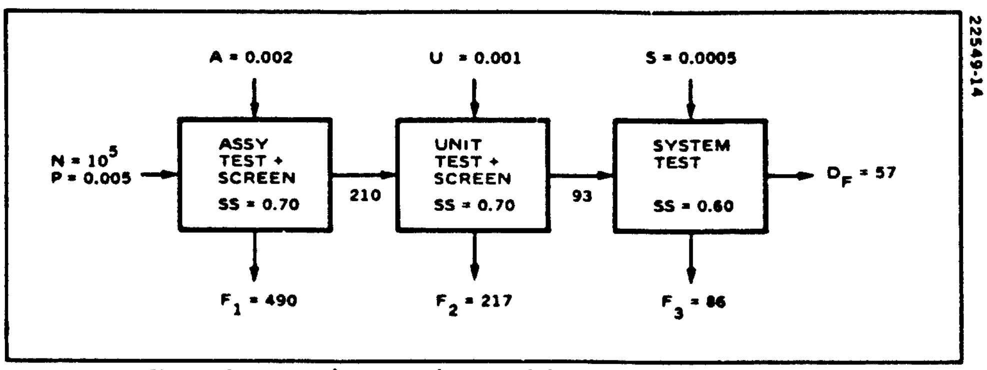

Figure 2.8. Production Flow Model With Stress Screening

The figure shows that there is significant increase in the number of defects precipitated at the assembly level, a moderate decrease at the unit level and a significant decrease at the system level.

The cost analysis of the effect of the stress screening for this example is shown in Table 2.1.

The table shows that the total manufacturing cost of repair without stress screening is $354.2K and the cost of repair with stress screening is $175.6. This indicates that if the cost of screening is less than $178.6K, a manufacturing cost savings results. (Also, the reduction in number of latent defects escaping to field use from 178 to 57 results in a potentially significant field maintenance cost savings).

Table 2.1 Manufacturing Stress Screening Cost Analysis Example.

	Assembly Level		Unit Level		System Level	
	W/O SS	W/SS	W/O SS	W/SS	W/O SS	W/SS
Number of Defects Precipitated	140	490	264	217	268	86
Cost per Repair	$50	$50	$300	$300	$1,000	$1,000
Repair Cost ($K)	7.0	24.5	79.2	65.1	268.0	86.0

Since the cost per repair estimates are expected to vary with type and complexity of hardware, Figure 2.9 shows the total assembly repair costs (per 1000 assemblies) as a function of cost per assembly repair. Figure 2.10 shows the total unit repair costs (per 100 units) as a function of cost per unit repair. Total cost is the product of cost per repair and expected number of repairs. The expected number of repairs is determined by the expected fraction of assemblies defective as a function of the initial part fraction defective, number of parts per assembly and number of assemblies per unit, explained in paragraph 2.2.3, below. Both figures show the repair costs incurred if all latent defects entering that level are precipitated, detected and eliminated at that level, which is unlikely since screening strengths are not expected to approach 100 percent. Some latent defects will escape to subsequent stages where repair costs are higher. Therefore, the repair costs shown represent the lowest cost to eliminate latent defects entering that level.

2.2.3 The Role of Part Level Screens

2.2.3.1 Part Failures in Field Use. The major portion of failures that occur in field use appears to be part failures as compared to workmanship failures, although during early life the split between part and workmanship failures is about equal. Figure 2.11 shows the changing distribution in failure types with time for a system development program. The early portion of the figure represents the later development stages and the later portion represents the final field testing stages.

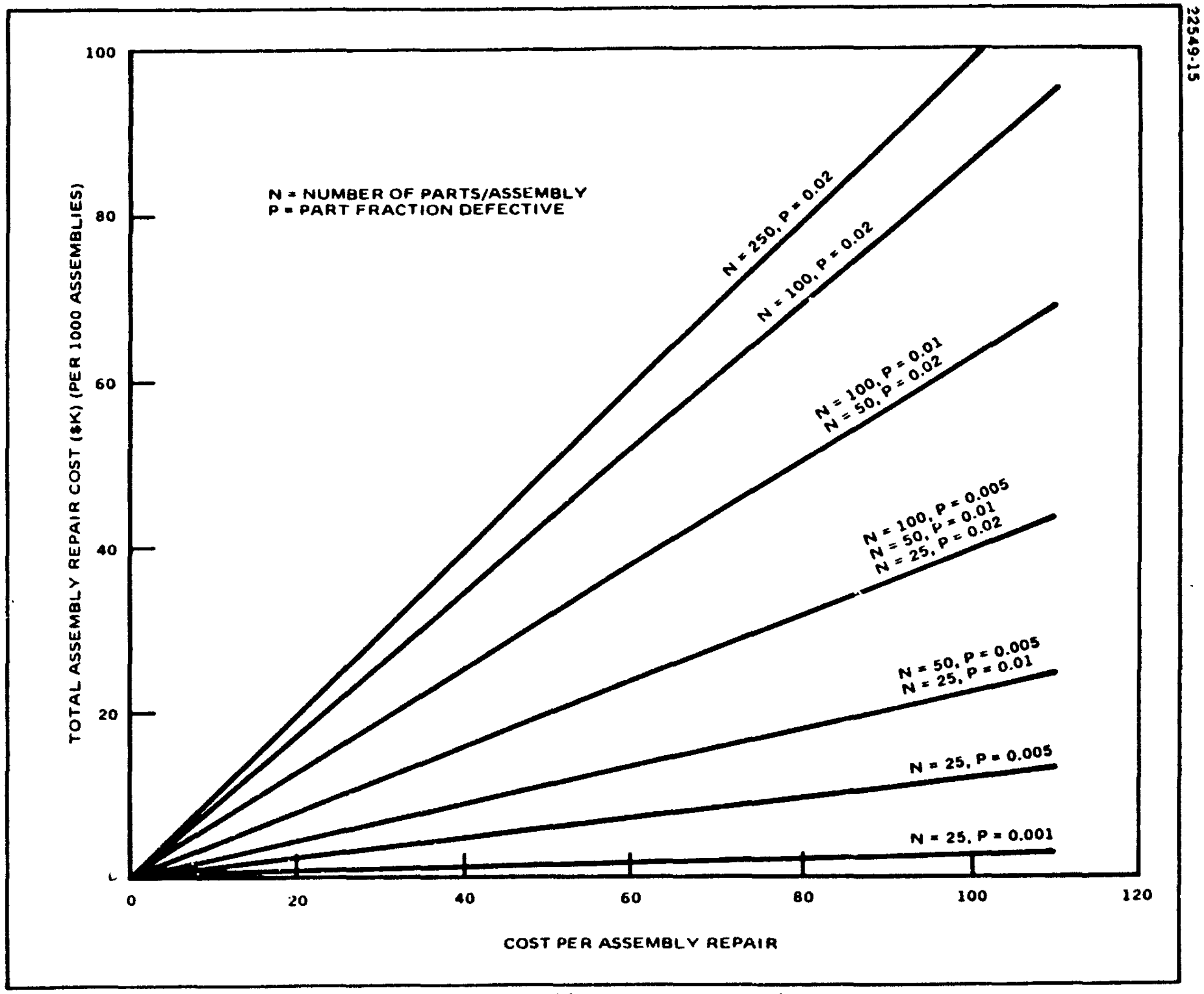

Figure 2.9. Assembly Repair Cost Analysis

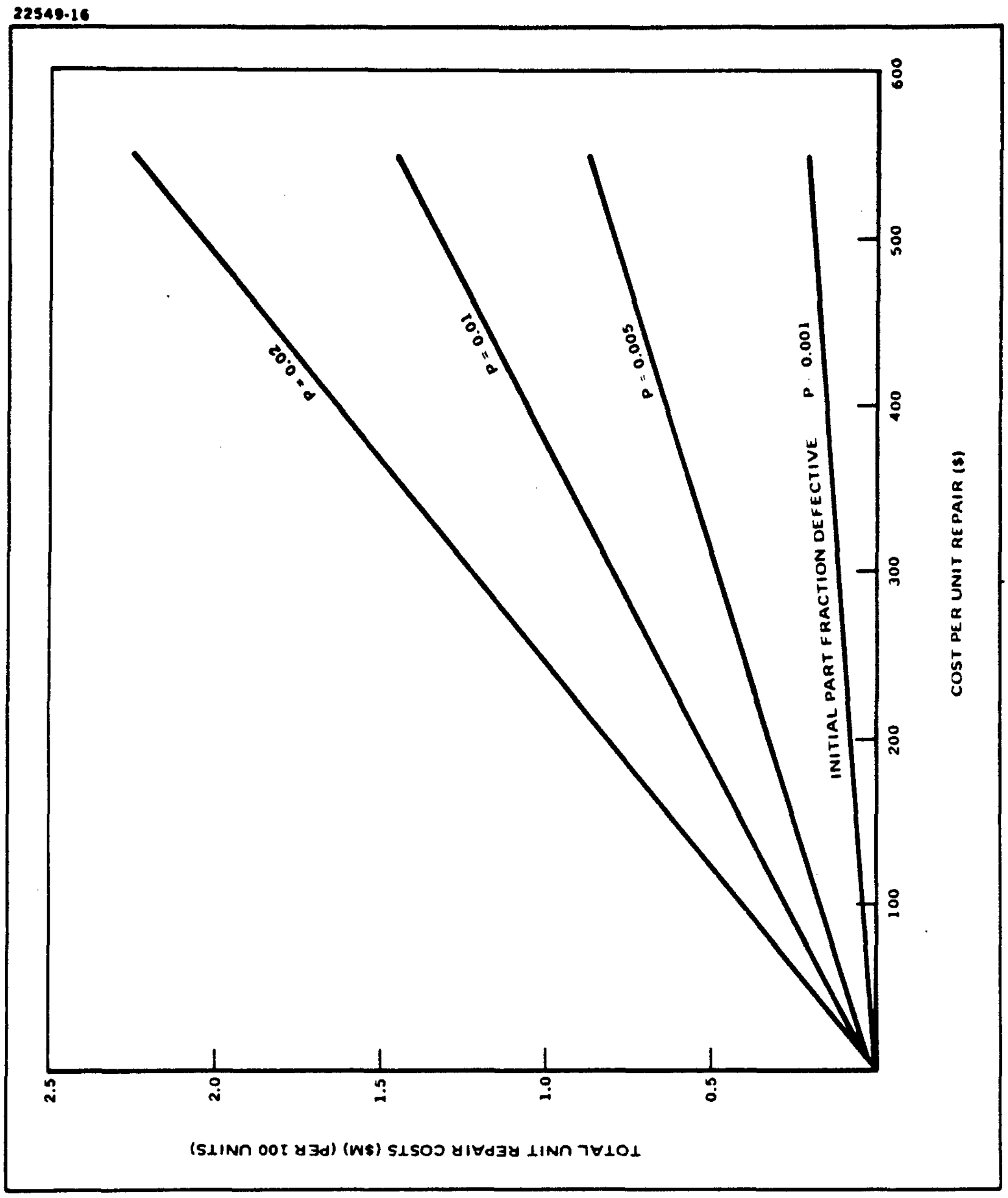

Figure 2.10. Unit Repair Cost Analysis

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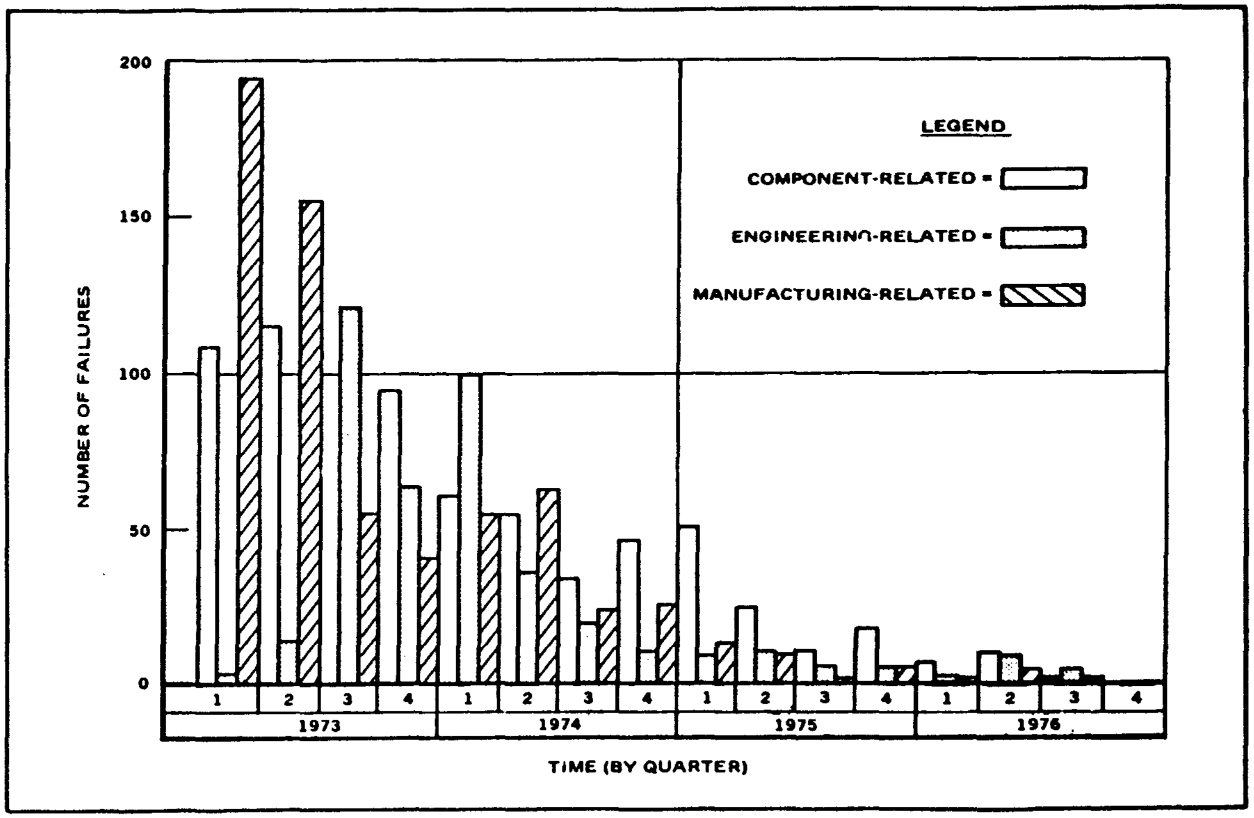

Figure 2.11. Distribution of Failures by Classification and By Time for a Radar Development Project

Design-related failures are a small fraction of the total number of failures in mature production systems. During development, however, the distribution is quite different as indicated by Figure 2-12. The figure shows the distribution of defects for three recent, large scale (25,000 to 47,000 parts/system) development programs over 2-3 years of field operation.

Part failures during production results in rework costs as described earlier. If parts are procured without screening and subjected to sample receiving inspection, the fraction defective may range from .01 to .20, depending on part type and quality grade. Even if the fraction defective is as low as .01 and the parts are installed on assemblies averaging, say, 50 parts, then about 40 percent of all assemblies produced will be defective (only one defective part can make an assembly defective). Figure 2.13 shows the expected fraction of assemblies defective as a function of number of parts per assembly and part fraction defective.

2.2.3.2 <u>Relationship of Part Fraction Defective to Quality Grade</u>. The failure rate of different populations of microcircuits, operating under identical conditions, can vary over an order of magnitude, depending on quality grade (Class S versus C-1). Yet, the major differences between the Class S die and the class C-1 die are the visual inspection acceptance criteria, level of process controls, and part-level screens and electrical tests to which the dice are subjected. Since screens and tests do not make devices more reliable (they improve lot quality by eliminating some latent defective parts), a "good" class C-1 die is as "good" as a class S die. Perhaps this can be extended to "good" class D-1 die as well. Therefore, it can be postulated that difference in failure rate of populations due solely to quality grade is a direct measure of the difference in fraction defective of those populations.

For example, consider a class S, hermetic flatpack MSI device of, say, 40 gates operating with T_j=25 deg.C in a benign ground environment. A failure rate of 0.0032×10^{-6} failures per hour is calculated. Let 5,000 of such devices be used in an end item expected to operate 50,000 hours. The expected number of device failures during the end item life is less than 1. For this application, this device can be considered "good" and if the population exhibited its calculated failure rate by having 0, 1, or even 2 failures, the population might be considered to be free of latent defectives. If a class C-1 device were used on the end item instead of the class S device, an additional 20 failures could be expected to occur during the same end item life, due solely to the difference in quality grade. Perhaps the additional 20 failures represent latent defectives in the population. If the class S parts were operated with T_j=100 deg. C instead of 25 C deg. the increase in failure rate would result in an additional two failures during the 50,000 hours. This may indicate that the

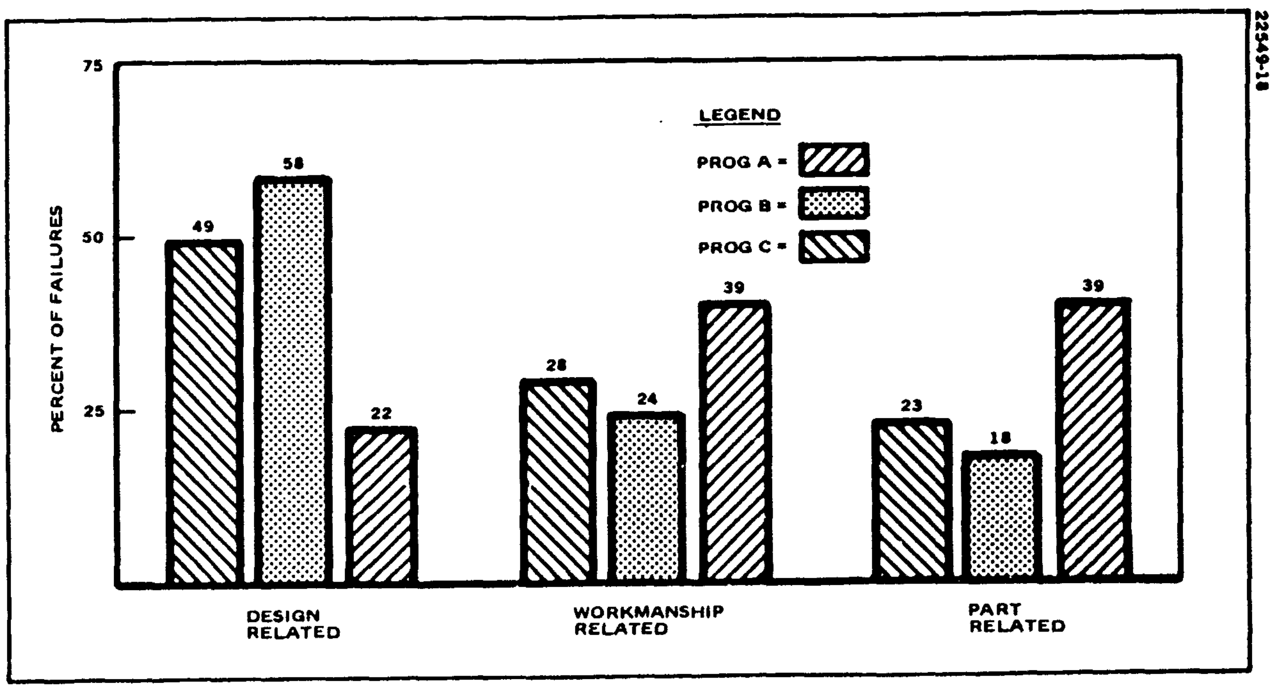

Figure 2.12. Distribution of Failures by Type for Three Recent Development Programs

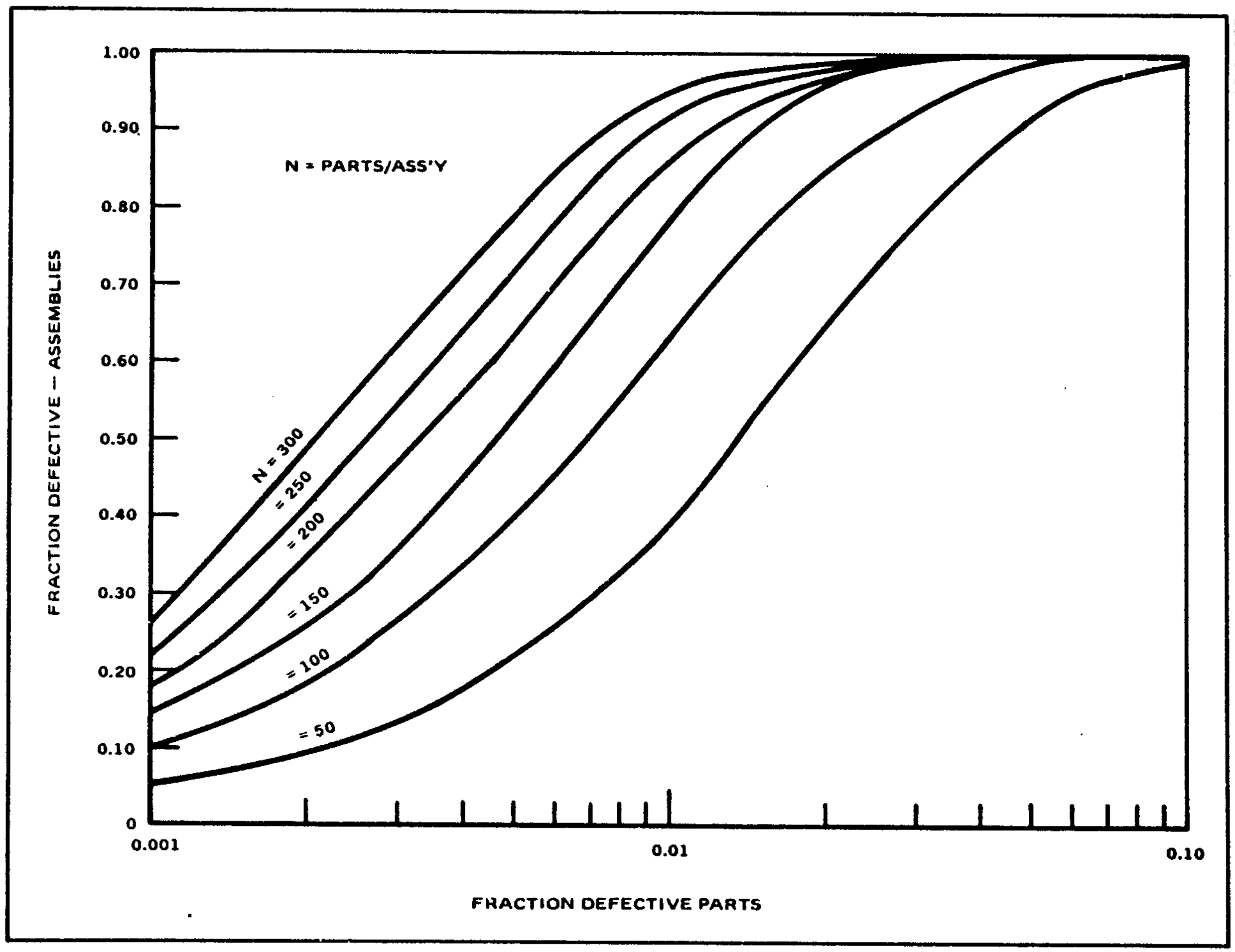

Figure 2.13. Fraction of Defective Assemblies as a Function of Initial Part Fraction Defective

class S lot contains latent defectives that were precipitated by the increased operating temperature. There can be no precise definition for a latent defective part because the inherent flaw which makes a part defective can range from a minor flaw (which may not be subjected to sufficient stress to cause degradation of the flaw to a hard failure) to a major flaw which requires only a slight stress. One view is that if a part fails during the life of the end item in which it resides it is, by definition, a latent defective part (excluding wearout failures). A device population containing a small fraction of defectives whose flaws range uniformly from minor to major would exhibit a decreasing failure rate until it reached a limiting population fraction defective,

$$p^* = \frac{p}{k(1-p) + p} \qquad (2\text{-}5)$$

k = ratio of defective part failure rate to good part failure rate

See Appendix E for a discussion of the limiting fraction defective. References 19 and 21 also discuss the decreasing failure rate characteristic relationship to defectives.

2.2.3.3 <u>Incoming Receiving Inspection and Test</u>. Microelectronic devices procured to the quality requirements of MIL-STD-883 receive 100% final electrical testing by the part manufacturer but, nevertheless, typically about 1 percent, and as much as 4 percent of the parts will not pass a similar electrical test performed at receiving inspection. There are several possible reasons for this, including:

- the seller's and buyer's tests are different
- seller testing errors
- buyer testing errors
- device damage or degradation in handling and transportation
- inspection and sorting errors

To determine what fraction of incoming microcircuit test rejects are actually defective, one manufacturer performed a retest of 525 rejects from a population of 75,981 devices tested. Results indicate that about 50% of the rejects are defective. Results are summarized in Table 2.2. Other studies indicate that without receiving inspection test, 60% of the defectives will be detected at the printed circuit board test, 10% will be detected at higher levels and 30% will not be detected (device applications not manifesting the defect).

TABLE 2.2 Results of Retesting Incoming Receiving Test Microcircuit Rejects

Supplier	# of Lots	Total Qty.	Rejects		Verified (See Note)		
			Total	%	Pass	Fail	% Fail
A	25	8525	100	1.17	62	32	0.38
B	8	8435	22	.26	15	7	0.08
C	17	21826	166	.76	120	46	0.21
D	30	27295	144	.53	35	102	0.37
E	22	9471	96	1.01	31	63	0.67
F	2	429	6	1.40	4	2	0.47
TOTALS	104	75,981	534	0.70	267	258	0.34

NOTE: 525 of the 534 rejects were retested. Percent failed shown in last column is the percent of the total quantity tested.

Table 2.3 shows recent experience with receiving inspection testing. The results in Table 2.3 for microcircuits show a slight increase in percent rejects over the figures in Table 2.2 due primarily to increased testing at elevated temperature (0.97% vs. 0.70%).

Table 2.3 Recent Receiving Inspection Test Results.

Part Type	Quantity	Average Quality	Rejects	Percent Rejected
Microcircuits	1,419,581	B-1	13,779	0.97
Discrete Semiconductors	343,000	TX	2,008	0.59
Passives	1,296,200	ER-M	8,539	0.66

The implication of the data in tables 2.2 and 2.3 is that populations of parts, even high quality parts contain defectives and if incoming receiving test is not performed then the estimate of the initial fraction defective (PDEF) must be appropriately adjusted when using the Stress Screening Model.

2.2.4 Manufacturing Process Defects

2.2.4.1 Sources of Defects. Both patent and latent defects are introduced during the fabrication, assembly and test processes of equipment in manufacture. The patent defects pass through the various assembly stages until detected by a test of sufficient thoroughness and all but the most subtle are detected and eliminated prior to shipment. Patent defects include the following:

- Parts
  - Broken or damaged in handling
  - Wrong part installed
  - Correct part installed incorrectly
  - Part failed due to EOS/ESD
  - Missing part
- Interconnections
  - Incorrect wire termination
  - Open wire due to handling damage
  - Wire short to ground due to misrouting or insulation damage
  - Missing wire
  - Open etch on PWB
  - Open plated-through hole
  - Shorted etch (solder bridge, loose wire strand)

Latent defects cannot be detected until they are transformed to patent defects through stress and time and stress screening is intended to effect this transformation. Latent defects include the following:

- Parts
  - Latent material or process defects
  - Partial damage through EOS/ESD
  - Partial physical damage in handling

- Partial damage during soldering (excessive heat)

- Interconnections
  - Cold solder
  - Inadequate/excessive solder
  - Broken wire strands
  - Insulation damage
  - Loose screw termination (lugs)
  - Improper crimp
  - Unseated connector contact
  - Cracked etch
  - Contact contamination
  - Loose conductive debris

2.2.4.2 Distribution of Defects. The quantity and distribution of manufacturing process defects are dependent on three basic factors;

- Density. Equipment with high part and/or wiring density is more susceptible to induced process defects due to smaller error margins and increased rework difficulty.

- Maturity. New production requires time to identify and correct planning and process problems, train personnel, etc. Maturity rate is dependent on volume and time. Low volume over a long time period has a low maturity rate.

- Process Control. Even with good process controls, low maturity and high density may result in sufficient process induced latent defects to justify stress screening. Maturity, with good process control, may eliminate the need for stress screening.

Because each manufacturer's production process is unique in terms of product types, technology, skills, and management and worker attitudes towards process control, there can be no single set of guidelines for process defect elimination with general applicability. Each manufacturer must examine his own conditions to determine the magnitude and nature of process induced defects and decide the appropriate, perhaps cost-effective, course for their elimination.

Table 2.4 shows a typical distribution of interconnection defects for printed wiring assemblies in early production, showing a 70/30 relationship of solder/etch defects and an overall defect rate of 0.2% defects per part. The table shows the defects that were detected without stress screening at the first opportunity (first assembly test).

Table 2.4 Interconnection Defects Detected at First Test for Early Production PWAs.

PWA Type	Qty.	Average Parts Per Assy.	Average IC's Per Assy.	Defects Detected Solder	Etch	Other	Total	Defects Per Assy.	Defects Per Part
Digital	8,160	85.73	41.33	1,343	638	7	1,988	0.244	0.0028
Analog	3,839	172.2	15.00	450	152	2	604	0.157	0.0009
TOTALS	11,999	113.4	32.91	1,793	790	9	2,592	0.216	0.0019

If it is assumed that the number of PWA interconnection defects per part increases linearly with an increasing percentage of integrated circuits, a reasonable assumption because IC's have more solder connections per part and solder defects dominate, then the data in Table 2.4 for digital and analog assemblies can be used to derive the linear relationship,

$$y = mx + b$$

$$m = \frac{\Delta \text{ in defects/part}}{\Delta \text{ in fraction IC's}}$$

$$= \frac{.0028 - .0009}{.4821 - .0871} = .0048$$

$$y - .0028 = .0048(x - .4821)$$

$$y = .0048\,x + .00049$$

where y is the interconnection defects per part and x is the IC fraction. The bounding values are .00049 when the PWA contains no ICs and .0053 when all parts are ICs.

Table 2.5 shows the distribution of part defects over a one-year period for multiple projects in various stages of maturity.

Table 2.5. Part Defects Detected at First Test for Production PWAs.

PWA Type	Qty.	Parts Per Ass'y.	ICs Per Assy.	Defects Detected			Defects Per Assy.	Detects Per Part
				Broken	Defective	Other		
Digital	41,879	108	35	876	14,426	15,532	0.736	0.00682
Analog	39,831	208	10	1,391	17,288	21,152	1.321	0.0048
Totals	81,710	157	23	2,267	31,714	36,684	0.865	0.0055

Using the same methodology as above, the defects per part as a function of the fraction of ICs is,

$$y = .00743x + .00444$$

where y is the part defects per part and x is the IC fraction. A review was made of unit wiring defects covering a one-year period. Results are shown in Table 2.6.

Table 2.6. Results of First Opportunity Wire Testing of Unit Wiring.

Time Period	Qty. Wires Tested	Qty. Wiring Defects	Fraction Defects	Defect Type	
				Cont.	Leak
Jun-Dec 1980	1,175,663	12,183	.0104	8,517	3,666
Jan-July 1981	1,104,211	11,830	.0107	7,584	4,246
Total	2,279,874	24,013	.0105	16,101	7,912

Tables 2.2 through 2.6 represent a relatively small sample of the nature and magnitude of defects to be expected in the manufacturing process and are provided only to allow the SSM user to establish starting points for part and workmanship defect values (PDEF and ADEF) where better information is not available.

2.2.5 Screen Selection and Placement

2.2.5.1 General Industry Consensus on Screen Selection and Placement. Because the origin of environmental stress screening was in AGREE testing, specifically temperature cycling and vibration of avionics "black boxes", the current general industry consensus is that temperature cycling is the most effective stress screen, followed by random vibration (Ref. 12). The vibration used in AGREE testing done in the past was single frequency and relatively low level (2.2g). In search of more effective screens, the Grumman experiments (Ref. 8) indicated that random vibration was more effective than either swept-sine or single frequency sine vibration. The results of thermal cycling in eliminating parts and workmanship defects (primarily during AGREE testing) were collected and summarized by Martin-Marietta (Ref. 7). The results of the two studies (Ref. 7, 8) were combined into NAVMAT P-9492 (Ref. 9) to serve as a starting-point guideline document.

At the module/assembly level, thermal cycling is believed to be an effective screen for both part and workmanship defects. The rate of change of temperature is thought to be an important parameter, with higher rate of change being more effective. Between 20 and 40 temperature cycles are generally recommended. There are two opposing schools of thought on whether power should be applied or not during the thermal cycling. There also is no general agreement on the effectiveness of vibration at the module/ assembly level. Experiments conducted at Hughes (Ref. 5, 6) indicated that vibration was not effective for printed wiring assemblies (PWAs). Ref. 20 states that PWAs can be effectively screened with broadband random vibration for certain defects.

At higher levels of assembly, i.e., units, groups, thermal cycling and random vibration are effective screens. Less thermal cycles are thought to be necessary at these levels, varying from 4 to 12 cycles. Power on is generally accepted as more effective and an increasing number of practitioners are recommending a performance verification test (PVT) at each temperature extreme. One report states that 80% of all defects detected during stress screening were found during PVT at the low temperature extreme. Several practitioners using random vibration at these levels cite power on and continuous monitoring as essential to detect intermittents. Low level single frequency vibration is widely accepted as being an ineffective screen.

There is some disagreement on the effectiveness of some screens at certain levels of assembly, the source of which may lie in differences in hardware type, construction, part content and degree of design and production maturity. Also, the definitions for the various levels of assembly (subassembly, assembly, module, unit, group, etc.) are not clear descriptions of the items they represent.

2.2.5.2 <u>Technical and Economic Factors to Consider in Selection and Placement of Screens</u>

2.2.5.2.1 <u>Factors to Consider in Assembly Level Screen Selection</u>. Assembly level screens are intended to accomplish two things,

1) precipitate latent defects which have escaped the part manufacturer's screens and receiving inspection tests, and

2) precipitate workmanship defects introduced in the process of assembly manufacture.

The types of latent part defects expected to be present depends on several factors, including,

1) types of parts comprising the assembly (i.e., microcircuits, discrete semiconductors, passive parts, low population parts, microwave parts, etc.)

2) quality grade of the parts

3) extent to which the parts were previously screened (e.g., receiving inspection tests and screens)

4) testability of the parts (e.g., microprocessor and other LSI devices are difficult to test completely and therefore precipitated defects may go undetected).

Table 2.7 is a summary of the expected types of defects for common part types. The table may be used to assist in the determination of the most effective screen to be selected based on the types of components that comprise the assembly to be screened. If, for example, the assembly consisted mostly of passive components, the table indicates that temperature cycling is the most effective screen, followed closely by burn-in. In this case, the choice of temperature cycling or burn-in should probably be made on a cost basis. Ref. 7 provides detailed breakdowns of typical failure modes and mechanisms for each major part type.

The types of latent workmanship defects expected to be present also depends on several factors, including,

1) assembly type (i.e., PWA or hard wired assembly)

2) assembly complexity (e.g., number of printed wiring layers, PTH density, metallization spacing, number of parts, wiring density, technology type)

3) type of parts used (flat pack vs DIP, hybrids vs discretes)

4) wire termination type (hand solder, wave solder, wire wrap, crimp)

5) design and production maturity.

Table 2.7. Distribution of Screening Methods for Various Classes of Parts. (Ref. 7)

	Percent Failure Modes Screened				
General Screening Method	Passive Components	Discrete Semiconductors	Monolithic ICs	Hybrid ICs	All Parts
Mechanical Shock	0	2.6	0	1.4	10.0
Particle Impact (PIND)	0	7.9	0	5.1	3.3
Random Vibration	10.4	7.9	15.6	10.9	11.0
Burn-In	63.6	36.8	35.6	43.5	51.9
Temperature Cycling	70.1	31.6	24.4	38.4	48.6
Temperature Soak	7.8	31.6	28.9	30.4	22.9
Temperature Shock	13.0	13.2	0	3.6	2.4
Power Cycling (ON/OFF)	13.0	13.2	0	3.6	7.1
High Pot.	2.6	0	0	0	1.0
Short Term Overload	39.0	0	0	0	14.3

The recommended method for estimating the expected quantity and type of latent assembly workmanship defects is to use experience data on assemblies of similar characteristics produced under similar conditions. Table 2.8 provides a brief listing of typical latent defect categories applicable to the assembly level and the types of screens thought to be effective in precipitating the defects. Table 2.8 may be used to assist in the selection of a screen type based on knowledge of prior workmanship defect types present in similar assemblies. The table indicates that vibration screens are effective for loose contacts, debris, loose hardware and mechanical flaws while thermal screens are not effective. Also, thermal screens are effective for defects relating to improperly installed parts, wire insulation, improper crimp and contamination while vibration screens are not effective. For other types of workmanship defects identified in the table, both thermal and vibration screens are effective.

Table 2.8. Assembly Level Defect Types Precipitated by Thermal and Vibration Screens

Defect Type Detected	Thermal Screens	Vibration Screens
Defective part	X	X
Broken part	X	X
Improperly inst. part	X	
Solder connection	X	X
PCB etch	X	X
Loose contact		X
Wire Insulation	X	
Loose wire termination	X	X
Improper crimp	X	
Contamination	X	
Debris		X
Loose hardware		X
Mechanical flaw		X

If a thermal screen (temperature cycling or constant temperature burn-in) is selected for the assembly level, the following screen parameters must be determined:

1) Maximum temperature - The maximum temperature to which the assembly will be exposed should not exceed the lowest of the maximum ratings of all the parts and materials comprising the assembly. Non-operating ratings for parts are higher than the operating ratings.

2) Minimum temperature - The minimum temperature to which the assembly will be exposed should not exceed the highest of the minimum ratings of all the parts and materials comprising the assembly.

NOTE: 1) and 2), above, must be carefully selected to assure that maximum screening effectiveness is achieved. Exceeding the maximum ratings may result in damage to non-defective parts or materials which is contrary to the principle of stress screening. If the operating temperature for a power-on screen cannot be readily determined analytically, a thermal survey of the item to be screened should be performed to determine the maximum and minimum screening temperatures.

3) Temperature rate of change - Screening effectiveness increases with increasing temperature rate of change. The maximum rate of change is dependent on the thermal chamber characteristics and the thermal mass of the items to be screened.

4) Dwell at temperature extremes - During a temperature cycle it is sometimes necessary to maintain the chamber temperature constant once it has reached the maximum (or minimum) temperature, sometimes referred to as dwell. Dwell may be required to allow the item being screened to achieve the chamber temperature. The item thermal lag depends on thermal mass and most PWAs have a low thermal mass. Figure 2.14 shows the part case temperatures tracking the chamber temperature very closely, therefore eliminating the need for dwell. PWAs with more mass may require some dwell or dwell may be required if a PVT or a vibration screen is to be imposed at a temperature extreme.

5) Number of Cycles - Ref. 12 recommends 20 to 40 thermal cycles for the assembly level. If the SSM is used, the number of cycles is determined by the required screening strength. (See Section 4).

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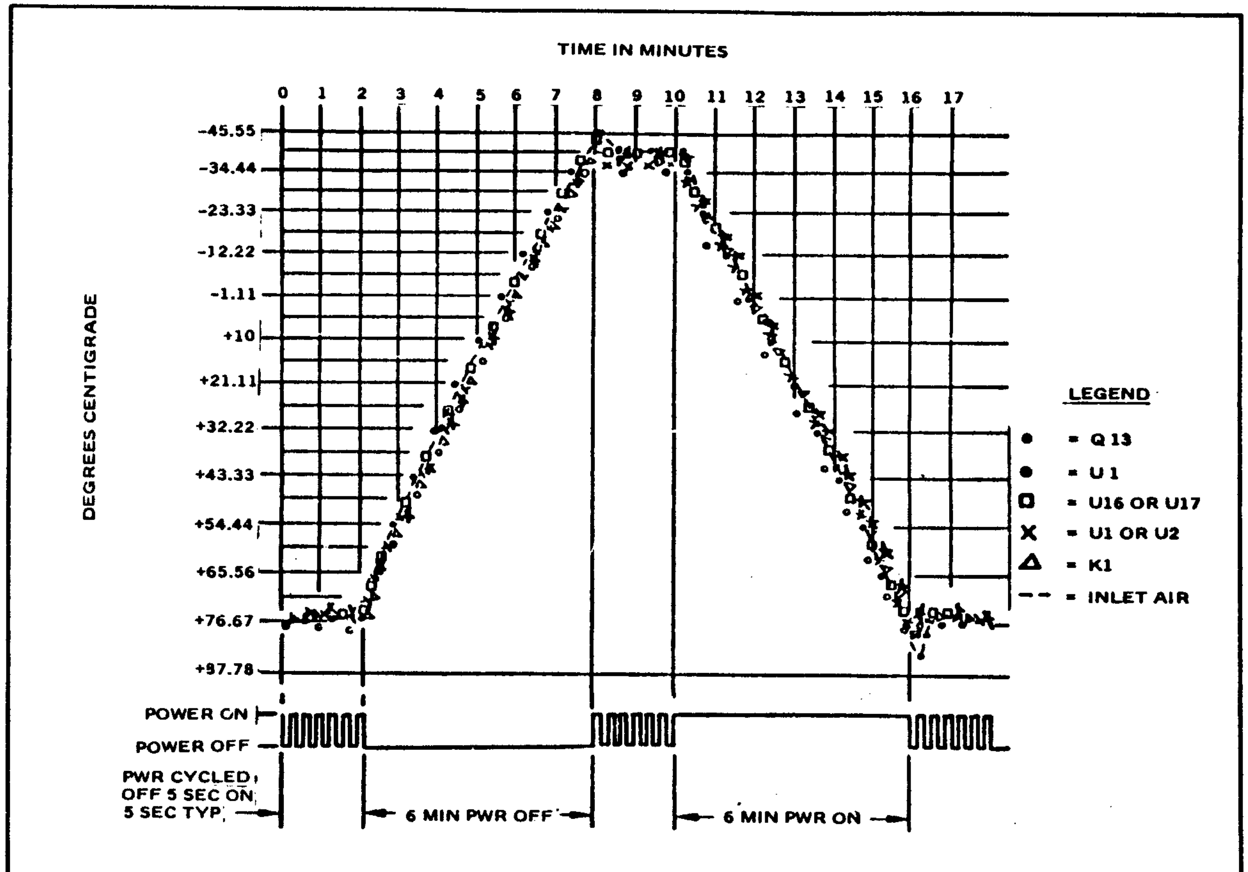

Figure 2.14. Card Thermal Survey. Part temperatures track the chamber temperature very closely. (Ref 5)

The determination of whether or not to apply power to assemblies being screened and whether or not to perform a functional test during the screen requires consideration of the following factors;

1) Predominant type of defect present - If the predominant type of defect is expected to be a weak interconnection which is transformed to an open circuit by the screen, (cold solder joint, weak wire bond) then a post-screen test will detect the open circuit and power-on is not required.

   If, on the other hand, the predominant type of defect is expected to be of an intermittent nature, then power-on with continuous performance monitoring is necessary.

2) Economics - A fixture and associated test equipment to house assemblies, apply power, provide stimuli, and monitor assembly performance can be costly. The tradeoff of fixture and test equipment cost and potential benefits may prove difficult.

   If a vibration screen is selected for the assembly level, the type of vibration (i.e., random, swept-sine or fixed-sine) must be selected and the following two parameters must be determined.

   1) Vibration level - Ref. 9, 12 and 20 recommend random vibration and suggest a level of .04-.045 g^2/Hz provided that the assembly can withstand that level without damage. If the assembly dynamic response characteristics to the vibration excitation are not known, a careful vibration survey should be conducted to properly establish the acceleration spectrum and level. Ref. 20 provides a procedure for conducting a vibration survey. Ref 12 suggests use of swept-sine as a second choice if random vibration cannot be performed. Single frequency vibration at the assembly level is considered as ineffective.

   2) Vibration duration - Ref. 9 and 12 suggest 10 minutes per each of three axes. The need for multiaxis excitation may vary from one assembly to another and therefore it is desireable to determine fallout per axis during initial screens to allow screen adjustments.

Some other factors to consider in determining the desireability of a PWA vibration screen are the PWA size and stiffness. Larger PWAs will flex more and precipitate such latent defects as cracked etch, cold solder and embedded conductive debris. Smaller PWA, particularly if conformally coated, are stiff and not amenable to vibration screening.

2.2.5.2.2 Factors to Consider in Unit Level Screen Selection. It is the intent of assembly level screens to precipitate latent part escapes and assembly workmanship defects. Unit level screens are then intended to precipitate unit workmanship defects and assembly level escapes. Unit level defect types vary with unit construction but typically include interconnection defects such as,

1) PWA Connector (loose, bent, cracked or contaminated contacts, cracked connector)

2) Backplane Wiring (loose connections; bent pins, damaged wire insulation, debris in wiring)

3) Unit Input/Output Connectors (loose or cracked pins, damaged connector, excessive, inadequate or no solder on wire terminations, inadequate wire stress relief)

4) Intra-Unit Cabling (Improperly assembled coax connectors; damaged insulation).

Units may also contain wired assemblies integral to the unit and not previously screened such as Power Control and BIT Panels, and purchased assemblies such as modular low voltage power supplies. The latent defects associated with those assemblies should be considered in the selection of screens.

Thermal screens are more effective than vibration screens in precipitating latent defective parts. Thermal cycling and vibration screens are both effective in precipitating latent workmanship defects although one screen may be more effective than the other for certain defect types. The unit composition and knowledge of prior screening will dictate the expected types of defects and aid in screen selection.

If a thermal screen is selected, the same process as described for the assembly must be followed. Differences are outlined below.

1) Units have greater thermal mass and therefore the higher temperature rates of change may be more difficult to achieve. A dwell at temperature extremes is probably required.

2) **Power-on screening is usually easily accomplished and widely recommended. A functional test (PVT) at temperature extremes has been shown in several cases to be effective in detecting defects not detectable at room ambient temperature. As stated previously, one project reported finding 80 percent of the total defects during PVT at low temperature.**

3) **Less temperature cycles appear to be required at the unit level. A range of 4 to 12 cycles is common.**

If a vibration screen is selected, it is very important that competent engineering personnel evaluate the unit to be vibrated to determine the appropriate vibration type, level of excitation and whether or not a vibration survey should be performed. There is some evidence that for large, massive units, low levels of vibration are effective screens.

2.2.5.3 <u>Pre- and Post-Screen Testing Considerations</u>. If an item is subjected to an unpowered screen, testing subsequent to the screen may reveal part or workmanship defects requiring correction. If the item was not tested prior to entering the screen it cannot be determined, even if a detailed failure analysis were performed, if the defects found were precipitated by the screen or were present in the item before the screen. If all the necessary information relating to the effectiveness of the screen were known, i.e., the average number of latent defects entering the screen and the average screening strength in precipitating those defects, it would not be necessary to know the condition of the item prior to screening. However, stress screening has not yet advanced to the point where quantity and type of latent defects can be accurately predicted and screening strengths calculated and therefore some degree of experimentation is necessary to precisely derive reasonable defect rate and screening strength estimates. Testing before entering a screen establishes a baseline upon which post-screen testing results can be used to measure the screening strength. The pre-screen testing should be done immediately before the screen to eliminate the uncertainty of latent defect introduction during such processes as cleaning, conformal coating, handling and storage which may follow the initial item testing.

Once the screening effectiveness has been established the value of both pre-screen and post-screen testing has diminished and it may prove cost effective to perform only post-screen testing. When major perturbations take place, such as production line changes, fabrication/assembly process changes, personnel changes or alterations to the stress screening process, it may be advisable to reinstitute pre-screen testing until the process has stabilized.

For long term production programs, the normal learning curves result in process improvements and the quantity and distribution of latent defects is expected to change accordingly. There will be a predominance of workmanship and manufacturing process related defects in early production and component related defects dominate mature production. Stress screens have a different degree of effectiveness for different defect types and therefore screens that may have been effective during early productions should be periodically re-evaluated to assure their continued effectiveness.

2.2.6 Planning a Stress Screening Program for the Development Phase

2.2.6.1 Characteristics of a Development Phase. A development phase may consist of a very advanced development in which a technical concept is being validated and the hardware used in the validation bears little resemblance to the production hardware. At the other extreme, a development phase may be late engineering development and the hardware is intended to be production prototype. Most often, a development phase will be somewhere in between the above extremes. When a high volume production program follows development, there may be a productization or production engineering phase (PEP) in which major hardware design changes are made to enhance producibility. Also, suppliers/vendors used in development may change for production. In short, if a stress screening program is considered for a development phase primarily for the purpose of gaining information for planning the production phase stress screening program, consider the amount of hardware changes expected and the relevancy of development phase screening results.

2.2.6.2 Pro's and Con's of Stress Screening in a Development Phase. As mentioned in the previous paragraph, one good reason for stress screening development hardware is to gain information about the nature and magnitude of latent defects in complex hardware items. This knowledge is valuable in planning how to cope with the problem in production. If a reliability demonstration test is required during development when a large number of latent defects are present in the hardware, a stress screening program may be the best way to reduce the number of defects and give a high probability of passing the test. On the other hand, the benefits to be derived from stress screening in development may not be worth the cost of implementation. During development there are many design related problems. About one-half of all failures are design or engineering-related. Also, there are many manufacturing related problems but may have no relationship to production problems because the development hardware may have been fabricated in an engineering model shop, from engineering sketches, with soft tooling, etc. Manufacturing-related problems are about 30% of the total. Only one of five confirmed failures in development is component related and many of these failures are a result of low quality part substitution for long-lead hi-rel parts. The hectic integration and checkout activity and the lack of disciplined electrostatic discharge/ electrical overstress (ESD/EOS) controls results in a predominance of electrical overstress failures. The combination of the above (numerous design and fabrication problems and electrical overstress failures) may tend to overshadow the latent defects during development and make stress screening of questionable value.

2.2.6.3 Relationship of Stress Screening and Reliability Growth. Reliability growth is achieved through the process of eliminating correctable defects. All design problems and some workmanship and component problems are correctable. When the proper corrective action is taken on correctable problems, the resultant hardware failures will not recur and the hardware manifests an improved MTBF, called reliability growth. Reliability growth in development can be enhanced through stress screening by precipitation of latent defects (early in the growth process). The latent defects eliminated through stress screening will not occur as random failures during later stages of the growth process.

2.2.7 Planning a Stress Screening Program for the Production Phase

2.2.7.1 Using Development Phase Results to Guide Production Phase Planning. As was pointed out in the preceding paragraph, determination of the effectiveness of stress screening in a development phase is difficult because latent defect failures are masked by a predominance of other failure types. Therefore, it is probably unrealistic to expect that accurate screening parameters can be derived for production phase screening from development phase screening results. However, valuable information can be gathered for the development phase which can be used to guide the planning for production. The most valuable information is:

1) Identification of hardware items (parts, assemblies, units, equipments, ...) which exhibited known or potential latent defects.

2) Identification of suppliers/vendors whose products show potential latent defect problems.

3) Assessment of the effectiveness of corrective actions taken to eliminate latent defects.

4) Known defective items, eliminated from production, the substitutes for which may require qualification testing and stress screening to assure the absence of latent defects.

5) The cost and schedule estimating factors for stress screening during development, and their applicability to production.

2.2.7.2 Initial Production Phase Start-up Problems. Typical start-up problems to be expected include the following:

1) Production personnel unfamiliarity with stress screening requirements.

2) Facilities and test equipment unavailable for stress screening.

3) Production planning errors result in incorrect screening and stress screening omissions.

4) Required stress screening data is not recorded or recorded incorrectly.

5) Schedule priorities preempt stress screening priorities.

6) Loss of failed parts preclude a sufficiently thorough analysis.

7) Excessive lag time from screened item failure to repair, making timely analysis of screening results difficult.

8) Factory test equipment breakdowns.

It is optimistic to state that all of the above problems can be avoided through careful planning but it is nevertheless correct to state that careful planning is the only hope to minimize them. The planning requires that all organizational activities in manufacturing involved in the stress screening be made aware of their roles and responsibilities at a time early enough that they are able to plan their functions and acquire the necessary resources to execute their responsibilities.

2.2.7.3 Planning for Subcontractor/Supplier Stress Screening. If it is determined that certain subcontractor/supplier items will require stress screening, the first decision to be made is whether the items are to be screened at the subcontractor's/ supplier's facility or screened by the prime contractor, either at receiving inspection/test or at a higher level of assembly. There are several benefits to screening at the subcontractor's/ supplier's facility,

1) Subcontractor/supplier concern for yield at screening, translated to profits, may force process improvements to minimize latent defects.

2) Screening at receiving inspection/test requires return of defectives to the subcontractor/supplier, and may result in shortages and concomitant schedule slips.

3) Special stress screening facilities and test equipment do not have to be acquired/supported/ operated by the prime contractor.

Few benefits of stress screening of a subcontractor/supplier item by the prime contractor can be identified.

To assure that the subcontractor/supplier is able to perform the required stress screening, it is important that the requirements are made known at an early enough time to allow him to acquire the necessary capability, or alternatively, arrange for an external laboratory to plan to perform to the requirements. This early planning is required to assure that the subcontractor/supplier is contractually required to perform the specified stress screening and record and report the results.

2.3 Contractual Considerations in Stress Screening

2.3.1 General Considerations. There are two views on stress screening that relate to contractual considerations. One view is that a stress screen or stress screening program is similar to a formal qualification or acceptance test, requiring contractual terms, formal test plans, procedures and reports. Contractually required failure free periods are appended to screens in this view and strong considerations are being given to coupling incentives to screening results. The second view is that stress screening is just another step in the production process to be applied selectively and temporarily as an effective method of eliminating latent defects and achieving cost savings and/or schedule improvement in the process.

It is not surprising that the first view is widely held by consumers while the second view is more common among producers. Consumers are primarily concerned with elimination of latent defects prior to acceptance to avoid the high cost of field repairs and to improve operational readiness. The producers primary concern is to optimize the production process by eliminating latent defects at the lowest possible assembly level, thereby effecting cost savings and avoiding schedule delays. If the producers process does not satisfy the consumers objectives, contractual terms must be executed to enhance the process.

2.3.2 Contractual Flexibility to Permit Stress Screening Program Adaptability. In early production, a number of unknowns preclude adoption of optimum stress screening. Some of the more significant unknowns are:

1) residual design deficiencies

2) manufacturing planning errors

3) worker training

4) new suppliers

5) latent defects in new part lots

6) new process capability

7) stress screening effectiveness

8) testability (for defect detection)

The stress screening program, even if carefully planned, may produce unexpected results which should be addressed though modification of the screens. The principle of adaptive screening is to adjust the screens on the basis of observed screening results so that the screens are always most cost-effective. Contract terms should be flexible enough to permit a modification of screens or screen parameters when such modification is shown to be beneficial to the consumer.

In long term production the quantity and distribution of latent defects changes with time and therefore contract terms should contain provisions for periodically reassessing the individual screens and the overall screening program. The overriding criterion for change should be the most cost-effective achievement of consumer objectives while remaining consistent with the optimum production process.

2.3.3 <u>Failure Free Cycles</u>. While currently used in some stress screening programs and apparently gaining in popularity, all that can be meaningfully said about failure free cycles is that some small measure of confidence is gained that the product is not totally devoid of merit. End-items being screened, say units, typically have inherent MTBFs of 500-5000 hours. Failure-free periods may range from 1-10 percent of the inherent MTBFs. Figure 2.15 shows the probability of passing a failure free period in 1, 2, or 3 tries as a function of the True MTBF-to-Inherent MTBF ratio. The figure clearly shows that items with low ratios (indicating many remaining latent defects) have a good chance of passing a failure free period. For example, an item which has only 1/10 of its specified MTBF has a 75 percent chance of passing a failure free period in 3 or less attempts.

2.3.4 <u>Incentives Associated with Stress Screening</u>. Many commercial products exhibit extremely good "field" reliability without having been contractually required to perform stress screening. For commercial producers, the producers objective stated in 2.3.1 is modified to include in the process optimization the least repair cost during the warranty period. Significant losses that might accrue through excess field repairs resulting from latent defect escapes must be avoided. Some commercial manufacturers employ forms of stress screening to precipitate latent defects while others concentrate more on process control and worker training and motivation.

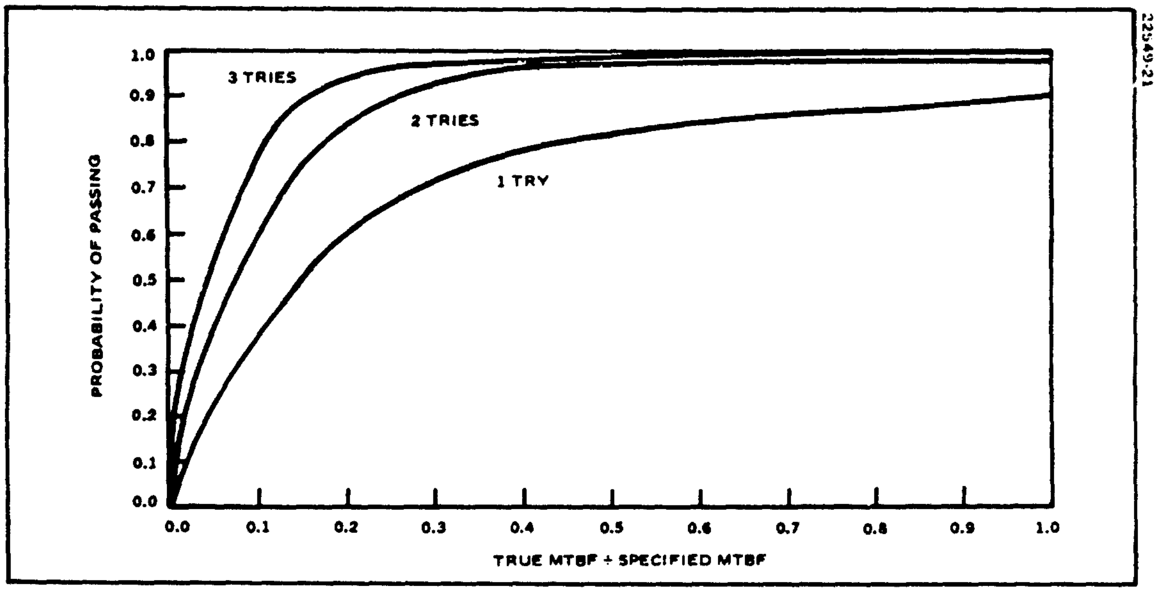

Figure 2.15. Probability of Passing a Failure Free Period of Duration 0.1 x Specified MTBF

The producers concern for potential losses (which may be stronger than his concern for potential gains) resulting from excessive maintenance in early fielding may be the necessary motivation for delivery of defect-free products, be it through stress screening or other means. The further pursuit of warranties, RIW contracts, guaranteed reliability, full contractor maintenance, etc., seems strongly justified.

3. DATA COLLECTION, ANALYSIS AND REPORTING

3.1 Data Collection. A stress screening program conducted during a development or early production phase will be concurrent with many other activities such as reliability improvements through design changes, quality improvements through manufacturing process changes, and supplier corrective action programs. The simultaneous activities will, collectively, result in a product improvement the credit for which may be difficult to assign. To gain assurance that the stress screening measures taken to improve reliability (or just to precipitate latent defects) are cost effective, it is important that the proper data be gathered and analyzed. This is particularly true if an adaptive stress screening program, where screening results are compared with pre-determined criteria, is employed. Data other than screening results is important for use in conjunction with the analysis of screening data, and includes,

- Qualification test results
- Supplier acceptance test results
- Part receiving inspection/test results
- Failure history
- Item inspection and test records.

3.1.1 Data Collection Requirements for Stress Screening Program. The determination of the specific data elements to be collected during a stress screening program can be made on the basis of the program objectives. Simple stress screening programs require little data other than the number of defects precipitated by the screen(s). When adaptive stress screening is conducted, considerably more data is required. The principle of adaptive stress screening is the change of the stress screens applied, on the basis of observed results, to achieve the most cost-effective elimination of latent defects. Therefore, adaptive stress screening requires data related to the effectiveness of the applied screens and the actual costs incurred.

The effectiveness of a stress screen can be measured by its screening strength, i.e., the probability that, given that a latent defect is present, the stress screen will transform the latent defect into a patent, or hard, defect and that defect will be detected by the screen. However, only the total number of defects found as a result of the screen is observable, which is insufficient to determine screening strength. The expected number of latent defects , F, precipitated by a screen is,

$$F = D \times \text{Screening Strength}$$

or the product of the screening strength and the number of latent defects entering the screen. The true values of D and screening strength are unknown. Further, the observed number of defects may not be totally comprised of precipitated latent defects but may include patent defects which have escaped prior screens. Another complicating, yet important, factor is that screening strength is a combination of the ability of the screen to raise a latent defect to a detectable level and the ability of the screen to detect it. The probability that a patent defect will be detected by the test to which the item being screened is subjected is called probability of detection, Pd, or detection efficiency. The value for Pd varies with the equipment complexity and the thoroughness of the test. Modern equipment comprised of microprocessors, large memory devices and other LSI devices may contain patent defects so subtle that only the most thorough of tests will detect them. The screening strength equations in the SSM are derived from screening experience with less complex equipment and therefore the screening strengths can be expected to be somewhat reduced for modern, complex equipments. Because there are many unknowns (e.g., initial part fraction defective, number of manufacturing defects introduced at each stage of assembly, the effectiveness of screens to precipitate the various types of latent defects, and the ability of equipment tests to detect precipitated flaws) in the art of stress screening, it is important to collect as much meaningful data as possible during the screening process so that analyses of the data may be helpful in developing better estimates for the unknowns. Some of the essential data elements are,

1) Defect data: Number of defects observed, time-to-failure or cycle-of-failure, failure classification (part, design, workmanship) and failure cause (to assist in discriminating between latent and patent defects and in determining corrective actions).

2) Screen Parameter Data: Recording of chamber temperature and the temperature of the item being screened during temperature cycling and constant temperature screens are important, at least initially, to ascertain that the chosen screen is actually being applied. For vibration screens, the vibration input and test item response are needed.

3) Cost data: Data related to the cost of conducting the screens and the cost of repairs due to precipitated latent defects, including, chamber/facility usage hours; labor hours; labor classifications.

Ref. 17 provides an extensive discussion of data collection during production with emphasis on the aspects of environmental stress screening.

3.1.2 The Role of Failure Analysis in Determining Screening Effectiveness. The effectiveness of a screen can be measured by the number of latent defects that are precipitated by the screen (fallout) and the number of latent defects precipitated at subsequent screens. The fallout at one level of screening is insufficient as a measure of effectiveness because the number of latent defects entering the screen is unknown. A comparison of fallout at successive screens provides a basis for estimating the initial quantity of latent defects and, therefore, effectiveness.

The total number of failures occurring during a screen (or detected at a post-screen test) are not all precipitated latent defects. Some are patent defect escapes from lower level testing. Examples of such patent defects would be manufacturing errors such as missing components, improperly installed components and wiring errors which were not detected at prior test/inspection levels. A failure analysis of the "fallout" data is necessary to segregate the manufacturing errors from the true part and workmanship defects and to further segregate the screen-induced defects (precipitated latents) from the patent escapes. In some cases a detailed failure analysis, including part autopsy, may be required to distinguish latents from patents and should be done if economically justifiable. Analysis in conjunction with test thoroughness investigation will help in establishing the assembly level at which the defect was introduced.

3.1.3 Analysis of Stress Screening Data.

3.1.3.1 Data Analysis for Monitoring the Stress Screening Program. Since a stress screening program is established for the purpose of precipitating latent defects and thereby improving early field reliability and, perhaps, saving production costs in the process, it is highly desireable, if not absolutely necessary, to gather and analyze stress screening data to determine if latent defects are being precipitated at the expected rate. An extensive review of stress screening literature conducted during the course of this study confirms that data collection and analysis is the most neglected aspect of stress screening. Inasmuch as it is widely recognized that estimating the number of latent defects present is, at best, difficult and there is considerable uncertainty about the ability of various stress screens to precipitate those defects, the importance of carefully examining the initial screening results cannot be over-emphasized.

The SSM can be used to assist in the analysis of data. The model calculates the expected fallout F, of any screen i by,

$$F = (D_i + ADEF_i) \cdot SS_i \cdot$$

where D_i = number of latent defects entering the screen at the ith assembly level

$ADEF_i$ = number of latent workmanship defects introduced at the ith assembly level

SS_i = screening strength of the ith screen

The SSM also calculates a probability interval, i.e., upper and lower bounds on the expected fallout. A .99 probability interval is computed by the model unless a different interval is requested by the user. See Appendix B for a theoretical discussion of the probability interval calculation. If the actual number of defects precipitated by the screen is within the desired probability interval, it can be concluded that the stress screening is proceeding as expected. If, on the other hand, the actual fallout lies outside the interval, an analysis of the data is indicated. The fallout data may either exceed the upper bound or fall short of the lower bound. When the upper bound is exceeded, four possibilities exist:

1) the screening strength may be greater than calculated by the model,

2) the estimate of the initial part fraction (PDEF) may be low,

3) the estimates of induced assembly defects (ADEF) may be low, or

4) the fallout may include patent defects that escaped detection in prior process steps.

To be able to determine which of the four possibilities is most likely, a thorough analysis of the actual fallout data is required. If the fallout data is predominantly part defects as compared to assembly defects, possibility 2) seems likely. Conversely, if assembly defects predominate, possibility 3) seems more likely. If the part and assembly defects are in the expected proportion but high, possibilities 1) or 4) may be selected. the same type of reasoning can be applied when the actual fallout falls short of the lower bound.

3.1.3.2 <u>Data Analysis for Evaluating the Stress Screening Program</u>. Stress screening programs may be costly to implement, and are justified by the resulting subsequent savings. Caution should be exercised to avoid commiting to a fixed stress screening regimen for a long production run on the basis of the initial cost-effectiveness analysis and early screening results. Time may bring about changes that impact on the cost-effectiveness of screening, such as changes in the magnitude and distribution of latent defects, cost of conducting screens, cost of repairs, and improved estimates of screening strengths. The SSM, with its optimization feature, can be used to determine a new set of screens or revised screening parameters that are more cost effective. Refer to the examples in Section 4.0 to see how the SSM can be used for this purpose.

The data analyses required for cost-effectiveness evaluation are,

1) revised estimates of part and assembly defects

2) adjusted equipment-related parameters of screening equations (using the adaptive feature),

3) revised estimates of screening cost (at this point, the fixed cost is sunk cost and may be excluded from the analysis),

4) revised estimates of repair costs at each level of assembly.

Data analysis during a production screening program serves another vital purpose besides determining the cost-effectiveness of the screening. Proper analysis of fallout data aids in identification of "correctable" defects which, if corrective action is taken to eliminate their source/cause, will not recur in subsequent production items. Elimination of correctable defects results in reduced fallout and lower production costs, which may indicate a need to alter the screens. Sufficient elimination of correctable defects may result in no further need for screening.

3.1.3.3 <u>Using the Chance Defective Exponential (CDE) Model to Evaluate Stress Screening Results</u>. Ref. 11 provides a method of temperature cycle screening data analysis which gives estimates of screening strength, initial fraction defective and constant failure rate. Figure 3.1 is an extract from Ref. 11 showing a sample histogram plot of unit average failure rate per temperature cycle. The per cycle data is used to develop maximum likelihood estimates (MLE), for parameters a_0, a_1 and a_2 using a constrained optimization computer program developed by McDonnell Aircraft Company.

The parameters of the CDE model (a_0, a_1, and a_2) are directly related to key unknowns (initial fraction defective, screening strength, latent defective fallout rate) vital to planning, monitoring and evaluating stress screening programs. Therefore, the CDE model is considered to have potential as an analytical tool for evaluating a screening program. The parameters are;

$a_0 = N\lambda g$, where N is the total number of parts in the item(s) subjected to stress screening and λg is the failure rate of good parts, i.e., parts without latent defects. a_0 then provides a measure of failure rate of the good parts subjected to the screen.

a_1 = Np, where p is the fraction of the part population that is latent defective. a_1 is then a measure of the total number of latent defective parts entering the screen.

a_2 = $k \lambda g$, where k is the ratio of the failure rate of latent defective parts to the good parts. a_2 is then a measure of the rate at which latent defectives precipitate into patent defects under the conditions of the stress screen, and therefore is a measure of the screening strength.

Obtaining estimates of a_0, a_1, and a_2, from actual screening fallout data allows the estimation of the vital screening program parameters. Since $a_0 = N\lambda g$, an estimate of a_0 provides an estimate of λg because N is known. Similarly, since a_1, = Np, an estimate of a_1 provides an estimate of p (fraction defective). Finally, an estimate of a_2 provides an estimate of k since an estimate for λg is derived from a_0.

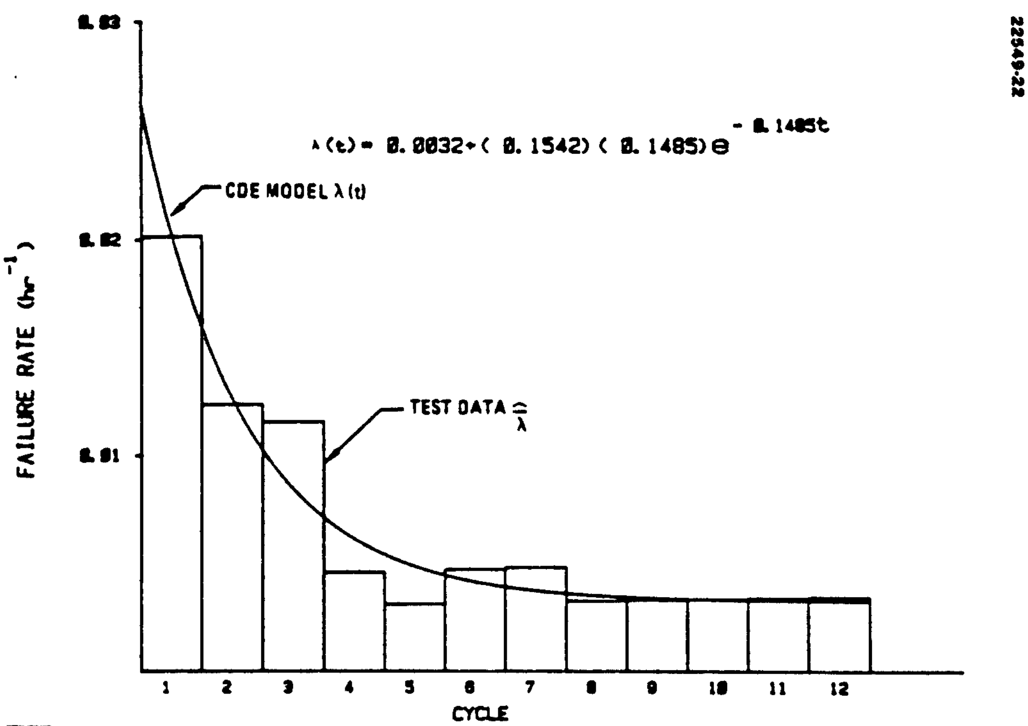

Figure 3.1. Temperature Cycling Data Fitted to the Chance Defective Exponential Model (Ref 11)

3.2 Reporting of Results

3.2.1 Purpose of Reporting Results. Timely reporting of the results of stress screening to cognizant management personnel is important to provide the necessary visibility regarding progress toward achieving the stress screening program objectives (achievement of a reliability requirement, manufacturing cost savings, field maintenance cost savings, or combinations thereof). Timely and accurate reporting allows decisions to be made regarding changes to the stress screening program for improved effectiveness or enhanced cost savings. Reporting also serves as a forcing function on the important tasks of stress screening data collection and analysis.

3.2.2 Reporting Methods. There are three basic methods of reporting results to management,

1) Periodic verbal reporting with visual aids,

2) Periodic written reports, ranging from informal, internal correspondence to formal, contractually required reports, and

3) Computer generated reports, either in hard copy form or image form on graphics terminals.

The verbal reporting method is most common and has the advantage of facilitating a question/answer exchange for report clarification. The disadvantage of this method is that it is more time consuming than the preparation of an informal report but this may be justified by the more effective information transfer. The verbal reporting is most desireable at the beginning of the stress screening program when there is the highest degree of uncertainty and highest management interest. As the stress screening program initial adjustments are effected and screening results are consistent with expectations, reporting should transfer to informal internal correspondence (e.g., weekly reports) and, perhaps, a formal monthly or bi-monthly report to the customer. The third reporting method is most efficient and is applicable during any phase of the stress screening program.

3.2.3 Report Content. The content of the reports should be tailored to the specific objectives of the stress screening program. If the primary objective is to achieve a reliability requirement, a reliability projection based on screening results is most appropriate. Cost data is always an appropriate reporting element and may include planned versus actual screening costs, manufacturing costs, or field maintenance costs. Below are some other typical reporting elements:

- Assemblies screened to date (total number of)

- **Assemblies passed screen without failure**
- **Assembly workmanship defects expected**
- **Upper and Lower Bounds**
- **Assemblies with 1, 2, ... defects**
- **Parts on assemblies screened**
- **Part defects detected**
- **Part defects expected**
- **Upper and Lower Bounds**
- **Assembly workmanship defects detected**
- **(Repeat of above for units, systems)**
- **Assembly yield**
- **Assembly repair costs**
- **Unit repair costs**
- **System repair costs**
- **Estimated part fraction defective**
- **Correctable failures**
- **Corrective action status**

4. THE STRESS SCREENING MODEL (SSM)

4.1. Description of the Model. The SSM is a modified version of the Screening and Debugging Optimization (SDO) Model (Ref. 1), the changes to which are described in paragraph 1.2 of this report. A simplified flow diagram depicting the stress screening process is shown in Figure 4.1 below. The figure shows (INCOMING) the total number of parts and number of defective parts entering a screening process. At level 1, some workmanship defects (ADEF) are introduced and the screen at level 1 has some screening strength (SS) which acts on the incoming part and workmanship defects to produce an expected fallout of part defects (PRT) and workmanship defects (WKM). The total number of defects entering a level minus the fallout is the number of residual defects passed on to the next level (DEF PASSED). After passing through the three screening levels, there are still some defective parts remaining (DEF P REM) and some workmanship defects remaining (DEF W REM), resulting in some instantaneous outgoing MTBF value. At each level there is an expected fallout and because of random variations in defect quantities and screening strengths, a probability interval with upper and lower bounds (UPPR BND, LOWR BND) is computed for monitoring purposes.

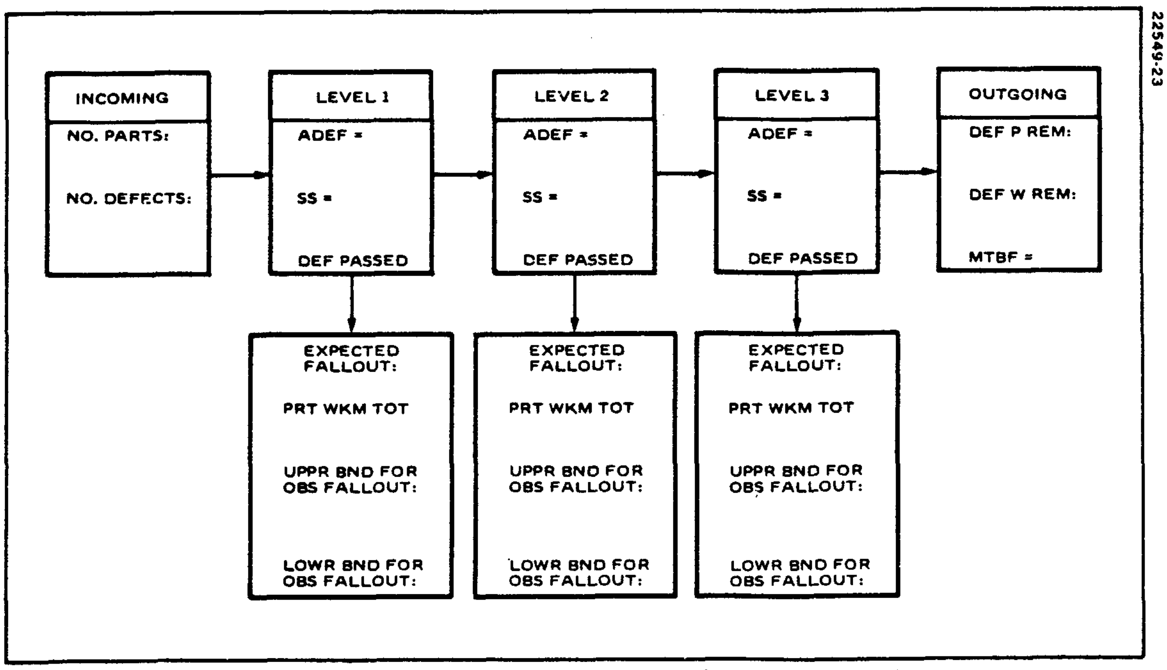

Figure 4.1. Stress Screening Model Representation of the Production Flow Process

4.1.1 Model Options. The SSM has three options, as follows:

1) MTBF Option (Option A). The SSM provides an optimum set of stress screens to precipitate the required number of latent defects to achieve a desired instantaneous MTBF at the termination of the screening.

2) Cost Option (Option B). The SSM provides a set of screens to precipitate the maximum number of latent defects for a fixed cost.

3) Trade-off Option (Option C). The SSM provides the capability to evaluate existing screens and to identify equivalent screens for trade-off purposes.

4.1.2 The MTBF Option. In this option, the user must input the desired MTBF of the item(s) to be screened and must also input the total number of parts comprising the item(s) and the expected number of latent defects. User input requirements and model default values are described in paragraph 1.5 below. The MTBF value must be a series MTBF (i.e., the sum of the failure rate of all parts subjected to the stress screen). The model may be used for a single system or for multiple systems. The total number of parts and MTBF must be adjusted accordingly. The model assumes that the MTBF is comprised of the reliability characteristics of good parts, with a failure rate λg, and latent defective parts, with a failure rate $k\lambda g$, good connections with a failure rate λc and defective connections with a failure rate $k\lambda c$, as follows:

$$\text{MTBF} = [(N-D)\lambda_g + Dk_1\lambda_g \ (M-C)\lambda_c + Ck_2\lambda_c]^{-1} \qquad (4\text{-}1)$$

where N = Total number of parts

D = Number of latent defective parts

k_1 = Defective part failure rate multiplier

M = Total number of connections

C = Number of latent workmanship (connections) defects

k_2 = Defective connection failure rate multiplier

The SSM uses equation (4-1) to determine the optimum set of screens that result in an MTBF equal to or greater than the desired MTBF.

4.1.3 The Cost Option. In this option, the user must input a fixed cost amount for which the SSM will identify a set of stress screens removing the largest number of defects.

4.1.4 The Trade-off Option. In those cases where a stress screening program has already been defined, the user may want to compare the overall cost and composite screening strength of the pre-defined screens with the optimum screens selected by the SSM. In this option, the user inputs the stress screen types and screen parameters and the SSM will compute the total cost and composite screening strength. This option also allows the determination of equivalent screens, i.e., if a given screen has some undesirable characteristics, an alternate screen of equivalent strength can be determined.

4.1.5 Description of User Inputs to SSM and Model Defaults. Table 4.1 lists the SSM data requirements and default values. The model prompts the user for the necessary data for the option chosen.

A ceiling cost (CREQD) for the screening program is necessary only for Option B. The model optimizes removal of the largest number of latent defects while staying under the ceiling cost.

The total number of parts, the failure rate of good parts, the failure rate of good connections, and the fraction of parts which are defective are necessary for all options. Defaults are available for all but the number of parts. Expected latent defects are discussed in Paragraph 4.1.6 below.

The screen sequence is entered by use of the screen numbers as indicated below:

Screen No.	Screen
1	Constant Temperature
2	Cycled Temperature
3	Random Vibration
4	Sine Sweep Vibration
5	Sine Fixed Vibration

Model defaults are:

Level 1 Cycled Temperature (1)

Level 2 Random Vibration (3)

Level 3 Constant Temperature (2)

TABLE 4-1. STRESS SCREENING MODEL USER INPUT DATA REQUIREMENTS
&
MODEL INPUT VALUES

Data Requirements	All	Option A	Option B	Option C	Program Symbol	Input Format	Units	Model Default Value
1. Desired Series MTBF		X			FRF	Integer	Hours	None,"(User Input Req.)
2. Cost Budget			X		CREQD	Real	Dollars	None
3. Total Part Population	X				NPARTS	Integer		None
4. Failure rate of good parts	X				XLAMP1	Real	Failures/ hour	1.x 10^{-7}
5. Failure Rate of Good Connections	X				XLAM01	Real	Failures/ hour	$1x10^{-10}$
6. Fraction of Parts Latent Defective	X				PDEF	Real	Fraction of total parts	.001
7. Screen Sequence	X				ISCR	Integer		ISCR(1)=2 ISCR(2)=3 ISCR(3)=1
8. Screen Parameters	*							
a) Constant Temp								
i) Temperature	X				AMAX 11	Real	°C	70° C
ii) Time	X				AMAX 12	Real	Hours	48 hours

* If a particular screen is used.

TABLE 4-1. STRESS SCREENING MODEL USER INPUT DATA REQUIREMENTS
&
MODEL INPUT VALUES

Data Requirements	All	Option A	Option B	Option C	Program Symbol	Input Format	Units	Model Default Value
b) Temp. Cycling								
i) Upper Temp.	X				AMAX 12	Real	°C	71° C
ii) Lower Temp.	X				AMAX 22	Real	°C	-54° C
iii) Rate of Change	X				AMAX 23	Real	°C/Min.	10° C/Min.
iv) No. of cycles	X				AMAX 24	Real	No. Cycles	20
C) Random Vibration								
i) g-level	X				AMAX 31	Real	g's	6 g
ii) Time	X				AMAX 32	Real	Minutes	10 Min.
d) Sine-Sweep Vib								
i) g-level	X				AMAX 41	Real	g's	6 g
ii) Time	X				AMAX 42	Real	Minutes	10 Min.
e) Sine-Fixed Vib								
i) g-level	X				AMAX 51	Real	g's	6 g
ii) Time	X				AMAX 52	Real	Minutes	10 Min.
9. Fixed Test Cost	X				A1	Real	Dollars	$0.00
10. Variable Test Cost	X				B1	Real	Dollars/hr	$30/hour
11. Repair Cost	X				B3	Real	Dollars	Level 1 = $45 Level 2 = $300 Level 3 = $990
12. Assembly Defects	X				ADEF	Real	Fraction of total	ADEF(1)= .002 ADEF(2)= .001 ADEP(3)= .0005

** If using to analyze fallout data.

TABLE 4-1. STRESS SCREENING MODEL USER INPUT DATA REQUIREMENTS
&
MODEL INPUT VALUES

Data Requirements	All	Option A	Option B	Option C	Program Symbol	Input Format	Units	Model Default Value
13. Number of Dropouts at each level **	X				AFALL or if analyzing parts & workmanship separately) APFALL AWFALL	Integer		None
14. Probability for probability interval.		X		X	PER	REal		0.99
15. No. of Faults Detected (Fallout)	X				NMF	REal		None
16. Times to Failure	X				T	REal		None

The SSM prompts the user for the test parameters in the chosen test. Table 4.2 identifies the parameters for each test.

TABLE 4.2 TEST PARAMETER CROSS REFERENCE

	TEST PARAMETER			
	No. 1	No. 2	No. 3	No. 4
1. Constant Temperature	Temp. Extreme (^oC)	Test Time (Hrs.)	-	-
2. Cycled Temperature	Upper Temp. (^oC)	Lower Temp. (^oC)	Temp. Rate Change (^oC/Min.)	Number Cycles
3. Random Vibration	Vibration G-level (g's)	Test Time (Min)	-	-
4. Sine Sweep	Vibration G-level (g's)	Test Time (Min)	-	-
5. Sine Fixed Vibration	Vibration G-level (g's)	Test Time (Min)	-	-

In Options A and B (MTBF and Cost) the user chooses all but the last parameter for all desired screens. An upper limit for a range is chosen for the final parameter. The model examines a grid of 5 points on each range. It then finds the optimal set of time and/or cycle parameters.

In Option C (Tradeoff) all parameters are fixed at user inputs. The model computes test strengths, costs, fallouts, etc.

When the screen equivalency capability is utilized only two screens are considered. All parameters in the given screen are fixed by the user. All but one selected parameter are fixed in the desired screen. The model finds the value for the variable parameter. This value yields a strength for the desired test equal to the strength for the given test. If this value cannot be achieved, a message is written and the user may enter new parameters.

The basic cost equation for each test is of a linear nature where:

test cost = fixed cost + (variable cost x test duration).

The default used for fixed cost in the SSM is zero due to the assumption that test equipment, etc. are already available to the user. For assembly and unit levels the actual time on test is multiplied by 15% since it was found in a previous study (RADC-TR-78-55) that this yields an approximation of actual labor hours. If the user wishes to alter the 15% constant its location is given in Appendix F.

Test duration is a test parameter in all but temperature cycling screens. The time required to reach the temperature extremes is computed by using the temperature rate of change parameter. It was found that the function

$$t_d = 4/dT \qquad (4-2)$$

where t_d = dwell time
dT = temperature rate of change (in oC/minute)

with units adjusted to yield hours, gave a good approximation of dwell time. Thus, test duration for temperature cycling is expressed.

$$d = 2N_{cyc}\,(t_t + t_d) \qquad (4-3)$$

where d = test duration

N_{cyc} = number of cycles

t_t = temperature transition time (minimum temperature to maximum temperature)

t_d = dwell time

In all cases test duration is computed in hours and the input or default variable cost is in dollars per hour. If the user does not input a variable test cost the default of $30/hour per hour is used.

The average cost to repair a defect found at each level may be input. The default repair costs are $45 at level 1, $300 at level 2, and $990 at level 3.

Total costs at each level are given by the linear equation;

$$C_i = C_{Ti} + F_i \cdot C_R \qquad (4\text{-}4)$$

where C_i = Total cost at level i

C_{Ti} = Test cost at level i

F_i = Number of latent defects precipitated (fallout) at level i

C_R = Cost to repair at level i (one repair per defect)

Workmanship defects introduced at each assembly level (ADEF (i), i=1, 2, 3)) are entered as a fraction of the number of parts.

If the SSM is being used to analyze fallout data this data can be entered for each screening level. The model examines the number of defects detected at each level to determine if it is consistent with the expected number. Parts and workmanship fallout can be analyzed separately at each level or a total can be used.

A probability value (PER) can be entered to change the 0.99 probability interval about expected fallout automatically assumed by the model. A smaller probability yields a narrower interval. That is, if the expected mean is the true mean, the band which contains 80% of the actual fallout is narrower than the band which contains 99%. It is suggested that the probability interval not be made too narrow (PER not less than .80). An overly narrow interval may frequently result in instructions to change the screen when a change is not required. If the planned mean is the true mean, then (1-PER) is the fraction of the time actual fallout will still be outside the interval. That is, (1-PER) of the time instructions will be given to change the screen even though no change is needed.

4.1.6 Determining the Initial Fraction Latent Defectives. An incoming lot of parts contains three subpopulations, viz.,

- parts that are "good", i.e., free of defects and are expected to survive the useful life of the end item of which they are a part, given that they are not subjected to stress beyond their ratings,

- parts that are "bad", i.e., containing a patent defect which precludes them from achieving their specified performance, and,

- parts that are "marginal", i.e., containing a latent defect which when initially tested appear to be "good" parts but when subjected to normal operating stresses and time will transform to "bad" parts.

If an electrical test is performed on a received lot of parts, the fallout from the test is expected to be all or most of the "bad" parts. The "marginal" parts are not expected to fail unless the operating stresses applied during the test and the test duration are sufficient to transform the "marginal" part to a "bad" part.

There is expected to be a good correlation between the quality grade of parts used and the initial quantity of "bad" and "marginal" parts. That is, higher quality grade parts are expected to have fewer "bad" and "marginal" parts. This is particularly true for microcircuits because the processing and final test and inspection requirements on the part supplier increase in severity for increasing quality grades, which serves to reduce the quantity of marginal parts and preclude delivery of bad parts.

Table 4.3, Initial Fraction Latent Defective Parts, is intended to provide the user with default values in those cases where better information is not available. The table contains values for type of equipment and quality level. The type of equipment is characterized by percentage of microcircuits,

$$\frac{\text{number of microcircuits}}{\text{total number of parts}} \times 100$$

Quality levels range from 1 to 8 and indicate the general quality grade of the equipment in terms of the various microcircuit, discrete semiconductor and passive part quality grades. The table values are derived through direct application of the values of MIL-HDBK-217C, Notice 1, for a typical part mix.

Table 4.4 provides a sampling of generic equipment types of recent vintage to aid the user in estimating the percentage of microcircuits that an equipment or system might contain if it can be related to one of the generic equipments.

TABLE 4.3 INITIAL FRACTION LATENT DEFECTIVE PARTS

Part Type	Quality Grades							
Microcircuits	S	B	B-1	B-2	C	C-1	D	D-1
Semiconductors	JTXV	JTX	Mixed	JAN/JTX	JAN	Mix. JAN/Non-Mil		Plastic
Passives	S	R	P	M/P	M	L/M	L	Com'l
Level	1	2	3	4	5	6	7	8
Percent Microcircuits								
100	.00086	.00173	.00520	.01120	.01378	.02240	.03015	.06030
90	.00101	.00229	.00683	.01427	.01935	.03442	.04871	.09084
80	.00116	.00284	.00846	.01735	.02492	.04644	.06726	.12138
70	.00130	.00340	.01009	.02042	.03048	.05846	.08582	.15192
60	.00145	.00395	.01172	.02349	.03605	.07048	.10437	.18246
50	.00160	.00451	.01335	.02657	.04162	.08250	.12293	.21300
40	.00175	.00506	.01498	.02964	.04719	.09452	.14148	.24354
30	.00190	.00562	.01661	.03271	.05276	.10654	.16044	.27408
20	.00204	.00617	.01824	.03578	.05832	.11856	.17859	.30462
10	.00219	.00673	.01987	.03886	.06389	.13058	.19715	.33516
0	.00234	.00728	.02150	.04193	.06946	.14260	.21570	.36570

4.2 Using the Model.

4.2.1 General Instructions for User. The Stress Screening Model consists of three programs designed to run interactively on a terminal.

> NOTICE: The third program, "Adapt", must be link-edited to the single precision IMSL library in order to run in its present form. See Step 5 of Section 4.2.2.

If a user has access to the IBM 370 TSO system (or equivalent) refer to paragraph 4.2.2. If not, the following general instructions describe the use of the Stress Screening Model.

TABLE 4.4 PARTS MIX FOR SAMPLE GENERIC EQUIPMENTS

GENERIC EQUIPMENT TYPE	PERCENT MICROCIRCUITS	QUANTITY OF PARTS: MICROCIRCUITS	DISCRETE SEMICONDUCTORS	PASSIVES	LOW POPU-LATION	TOTAL
SHIPBOARD DISPLAY CONSOLE	54.3	4228	1528	1889	137	7782
MILITARIZED LARGE COMPUTER	44.0	4598	428	5063	354	10,443
MILITARIZED MINI COMPUTER	39.0	814	23	1180	71	2,088
SHIPBOARD INTERFACE UNIT	37.8	4785	1016	5556	1300	12,657
RADAR OPERATIONS VAN	35.5	5361	1051	8294	388	15,094
RADAR VIDEO PROCESSOR	34.4	3206	385	4837	896	9324
SUBMARINE DISPLAY CONSOLE	32.2	5963	1807	10,270	450	18,490
TORPEDO GUIDANCE AND CONTROL	31.9	6806	1483	12,653	412	21,354
SHIPBOARD INTERFACE UNIT	29.4	7787	2367	15,126	1200	26,480
AIRBORNE COMMUNICATIONS TERMINAL	24.7	3864	1352	9752	705	15,673
SHIPBOARD SEARCH RADAR	19.2	3713	2381	10,522	2700	19,316
COMPUTER PERIPHERAL (MAG TAPE UNIT)	18.6	214	194	737	4	1149
SHIPBOARD SEARCH RADAR	16.2	2420	1794	10,139	571	14,924
AIR DEFENSE DISPLAY CONSOLE	16.0	1685	1074	6637	1104	10,500
GROUND MOBILE RADAR	14.9	878	798	3882	344	5902
SUBMARINE INTERFACE UNIT	8.6	515	2657	2484	354	6010
TOTALS		56,837	20,338	109,021	10,990	197,186

The three FORTRAN IV programs (PREFIX, SD01, and ADAPT) comprise the SSM and together require nine working data sets for operation. These data sets should be "card image" (i.e., record length of 80 characters) with appropriate blocking (consult your installation requirements) and should be assigned FORTRAN IV data set reference numbers 2, 4, 8, 9, 10, 11, 12, 13, and 17. While the names assigned to these data sets are irrelevant to the operation of the programs, the naming conventions used in paragraph 4.2.2 are recommended. They are consistent with the data sets in a previous version of the SSM (RADC-TR-78-55).

The next step is to assemble the required input data using Table 4.1 as a guide. Having allocated the working data sets, the next step is to run the programs PREFIX, SD01, and ADAPT, in that order. The programs will prompt the user for all input data which has been assembled.

4.2.2 IBM 370 TSO User Instructions. Figure 4.2 is a simplified flow diagram of the SSM. The following instructions describe the five steps necessary for initial use of the SSM.

Step 1. Using the program listings in Appendix F, create PREFIX.SDO.LOAD, SD01.LOAD, and ADAPT.LOAD. Recall that ADAPT.OBJ should be link-edited to the single precision IMSL library when forming ADAPT.LOAD. ADAPT.OBJ is the object program compiled from the source program ADAPT.FORT.

Step 2. Create the empty data sets PROGRM.DATA, PD.DATA, F.DATA, R.DATA, AB.DATA, LIMITS.DATA, OPS.DATA, FTIME.DATA, and ADAPT.DATA. The user is not required to enter data directly into these files. All data is entered interactively. The data files are reused each time the model is executed. Thus, once they are created, they may be ignored by the user. They are only used to transfer data from one program to the next.

Step 3. Assemble required data. Using Table 4.1 as a guide, determine user-unique values, default values, etc. Also see the examples which follow.

Step 4. Execute the CLIST:

```
000010 FREEALL
000012 ALLOC FI(FT02F001) DA(ADAPT.DATA)
000020 ALLOC FI(FT04F001) DA(PROGRM.DATA)
000030 ALLOC FI(FT11F001) DA(PD.DATA)
000040 ALLOC FI(FT08F001) DA(F.DATA)
000050 ALLOC FI(FT09F001) DA(R.DATA)
000060 ALLOC FI(FT10F001) DA(AB.DATA)
000070 ALLOC FI(FT12F001) DA(LIMITS.DATA)
000080 ALLOC FI(FT13F001) DA(OPS.DATA)
000085 ALLOC FI(FT17F001) DA(FTIME.DATA)
```

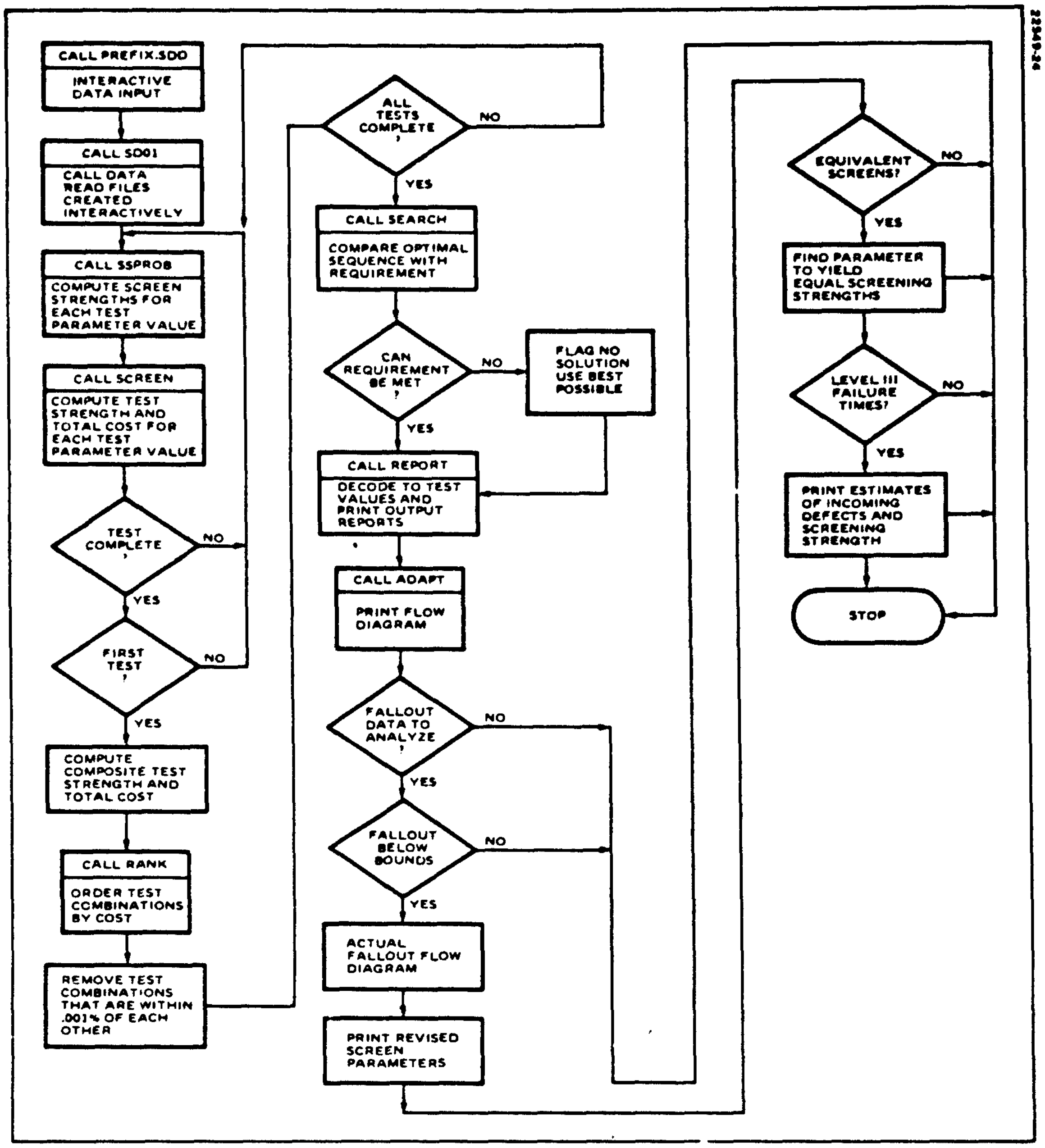

Figure 4.2. Flow Diagram of the Stress Screening Model

```
000090 CALL PREFIX.SDO.LOAD(TEMPNAME)
000100 CALL SDO1.LOAD(TEMPNAME)
000105 CALL ADAPT.LOAD(TEMPNAME)
000110 END
```

Step 5. Enter data as prompted. Once data is input, the optimization and flow chart output will be printed without further action from the user. If there is actual fallout data to be analyzed, the user will be prompted. If equivalent screens are to be found, the parameters will be called for.

For subsequent use, only steps 3, 4, and 5 will be necessary for use of the model since the load modules and data sets are on file. The examples which follow illustrate some of the possible options.

Two proprietary routines are used in the model. If IMSL is not already available the user may wish to contact

International Mathematical and Statistical
Libraries, Inc.
Sixth Floor - NBC Building
7500 Bellaire Boulevard
Houston, Texas 77036

Telephone (713) 772-1927
Telex 79-1923 IMSL INC HOU.

The IMSL routine MDCH is used in the computation of the bounds for actual fallout in this program. As stated previously, ADAPT.OBJ needs to be link-edited to the single precision IMSL library in order to run in its present form.

The use of MDCH is as follows:

CALL MDCH(CS, DF, P, IER)

where

CS = input value for which the probability is computed. CS must be greater than or equal to zero.

DF = input value containing number of degrees of freedom of the chi-squared distribution. DF must be greater than or equal to .5 and less than or equal to 200,000.

P = output value containing probability.

IER = error parameter. Terminal error = 128 + N. N=1 indicates that CS or DF was specified incorrectly.

Warning error = 32 + N. N=2 indicates that the normal PDF would have produced an underflow.

MDCH computes the probability P that a random variable X which follows the chi-squared distribution with continuous parameter DF, is less than or equal to CS.

Any chi-squared routine with similar input and output parameters could be substituted if access to the IMSL library is not available.

The two lines -

```
CALL MDCH (X1,B(I),P,IER)                    BOUN 300

CALL MDCH (X1,B1,P1,IER)                     BOUN 360
```

found in ADAPT.FORT would be the only program lines changed if a different library routine is used.

A Newton-Raphson root-finding technique is used to obtain the degrees of freedom since no available routine could do that directly.

The IMSL Routine ZXSSQ is used for the least squares fit of failure times to the CDE model. Parameters a_1 and a_2 of the CDE model are estimated. Fairly extensive rewriting will be necessary if a different curve-fitting routine is to be used. However, if times to failure for level III are not to be analyzed, ZXSSQ is not needed. The line calling ZXSSQ (OPT 200 in ADAPT) may be removed in this case.

4.3 Examples of SSM Use

4.3.1 MTBF Option Examples

4.3.1.1 Planning a Stress Screening Program to Achieve a Certain MTBF, without Pre-established Screens. The user in this example specifies an MTBF of 1200 hours and selects the model default screens at the assembly, unit and system levels. The least cost Thermal cycling screen at the assembly level and random vibration screen at the unit level to achieve the desired MTBF is determined by the SSM. A screen at the system level is determined not necessary to achieve the 1200 hour MTBF value.

```
******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

   IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

   OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
    RELIABILITY REQUIREMENT

   OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

   OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS


   DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
   ENTER ZERO)
?
1200

   TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
5000

   FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
    PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

DEFAULTS ARE:

LEVEL 1	LEVEL 2	LEVEL 3
TEMP. CYCLING	RAN.VIB	CONST. TEMP.
(2)	(3)	(1)

IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:

?

0

```
********LEVEL 1********

     TEMPERATURE CYCLING, LEVEL 1
     THE DEFAULT VALUES ARE:
     LOWER TEMP=-54 DEG C
     UPPER TEMP=71 DEG C
     TEMP. RATE OF CHANGE=5 DEG C/MIN
     RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
     IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

     ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

     IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

     FIXED TEST COST IN DOLLARS=
?
0
     VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
     AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
     ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 2********

RANDOM VIBRATION, LEVEL 2
THE DEFAULT VALUES ARE:
G-LEVEL=6 G
RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0
VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
                    ********LEVEL 3********

   CONSTANT TEMPERATURE, LEVEL 3
   THE DEFAULT VALUES ARE:
   TEMPERATURE=70 DEG C
   TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
   IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT,ENTER 1:
?
0

   ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

   IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

   FIXED TEST COST IN DOLLARS=
?
0
   VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
   AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
   ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
0


   IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1
```

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
5000	3	5.	0.0	1200.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	10.
2	5.
3	3.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

T E S T   D E S C R I P T I O N

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						450.
TEST NO. 2	CYT	71.00	-54.00	5.00	5.00	450.
LEVEL NO. 2						1955.
TEST NO. 3	RVIB	6.00	7.50	0.0	0.0	1955.
LEVEL NO. 3						0.
TEST NO. 1	CT	0.0	0.0	0.0	0.0	0.
TOTAL COST					$	2404.

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS :	WORKMANSHIP 5.	6.	7.	8.	9.	10.	11.
0. :	1956.	1955.	1955.	1955.	1954.	1954.	1954.
0. :	1956.	1955.	1955.	1955.	1954.	1954.	1954.
1. :	1586.	1586.	1586.	1586.	1585.	1585.	1585.
2. :	1204.	1204.	1204.	1204.	1204.	1204.	1204.
3. :	971.	971.	971.	970.	970.	970.	970.
4. :	813.	813.	813.	813.	813.	813.	813.
5. :	699.	699.	699.	699.	699.	699.	699.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
1
ENTER PROBABILITY DESIRED:
?
.8

STRESS SCREENING FLOW DIAGRAM

```
-----------   -----------   -----------   -----------   -----------
: INCOMING :  : LEVEL 1  :  : LEVEL 2  :  : LEVEL 3  :  : OUTGOING :
-----------   -----------   -----------   -----------   -----------
:#PARTS:   :  :ADEF=     :  :ADEF=     :  :ADEF=     :  :DEF P REM::
:      5000:  :       10.:  :        5.:  :        3.:  :        2.:
:          :-->:         :-->:         :-->:         :-->:         :
:#DEFECTS: :  :TS=       :  :TS=       :  :TS=       :  :DEF U REM::
:        5.:  :     0.403:  :     0.466:  :      0.0 :  :        8.:
:          :  :          :  :          :  :          :  :          :
:          :  :DEF PASSED:  :DEF PASSED:  :DEF PASSED:  :MTBF:     :
:          :  :        9.:  :        7.:  :       10.:  :     1204.:
:          :  :          :  :          :  :          :  :          :
-----------   -----------   -----------   -----------   -----------
                   :             :             :
                   :             :             :
                   V             V             V
             ------------- ------------- -------------
             :           : :           : :           :
             : EXPECTED  : : EXPECTED  : : EXPECTED  :
             : FALLOUT:  : : FALLOUT:  : : FALLOUT:  :
             :           : :           : :           :
             : PRT UKN TOT: : PRT UKN TOT: : PRT UKN TOT:
             : 2.  4.  6.: : 1.  6.  7.: : 0.  0.  0.:
             :           : :           : :           :
             :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
             :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
             :           : :           : :           :
             : 5.  8. 10.: : 3.  9. 11.: : 0.  0.  0.:
             :           : :           : :           :
             :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
             :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
             :           : :           : :           :
             : 0.  1.  2.: : 0.  2.  2.: : 0.  0.  0.:
             :           : :           : :           :
             ------------- ------------- -------------
```

INTERVAL MTBF

TIME	MTBF
2000.	1219.
4000.	1233.
6000.	1247.
8000.	1261.
10000.	1275.
12000.	1288.
14000.	1302.
16000.	1314.
18000.	1327.
20000.	1339.

```
    IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?

1
    IF YOU HAVE SEPARATE FALLOUT FOR PARTS AND WORKMANSHIP ENTER ONE
    IF YOU HAVE TOTAL FALLOUT ONLY AT EACH LEVEL, ENTER ZERO:
?
1
    ENTER, IN ORDER, ACTUAL FALLOUT:
    DUE TO    (A) PARTS    (B) WORKMANSHIP, AS PROMPTED:
    FOR LEVEL 1:
?
1 0
    FOR LEVEL 2:
?
1 4
    FOR LEVEL 3:
?
0 0
```

STRESS SCREENING RESULTS:

```
-----------   -----------   -----------   -----------   -----------
: INCOMING :  : LEVEL 1  :  : LEVEL 2  :  : LEVEL 3  :  : OUTGOING :
-----------   -----------   -----------   -----------   -----------
:#PARTS:   :  :ADEF=     :  :ADEF=     :  :ADEF=     :  :DEF P REM::
:     5000:   :      10.:   :       5.:   :       3.:   :       3.:
:         :-->:         :-->:         :-->:         :-->:         :
:#DEFECTS: :  :TS=       :  :TS=       :  :TS=       :  :DEF U REM::
:       5.:   :    0.067:   :    0.466:   :    0.0   :  :      10.:
:         :   :         :   :         :   :         :   :         :
:         :   :DEF PASSED:  :DEF PASSED:  :DEF PASSED:  :MTBF:     :
:         :   :      14.:   :      10.:   :      13.:   :     900.:
:         :   :         :   :         :   :         :   :         :
-----------   -----------   -----------   -----------   -----------
                   :             :             :
                   :             :             :
                   V             V             V
            ------------- ------------- -------------
            :           : :           : :           :
            : EXPECTED  : : EXPECTED  : : EXPECTED  :
            : FALLOUT:  : : FALLOUT:  : : FALLOUT:  :
            :           : :           : :           :
            : PRT UKN TOT: : PRT UKN TOT: : PRT UKN TOT:
            :  0.  1.  1.: :  2.  7.  9.: :  0.  0.  0.:
            :           : :           : :           :
            :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
            :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
            :           : :           : :           :
            :  0.  3.  3.: :  5. 11. 14.: :  0.  0.  0.:
            :           : :           : :           :
            :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
            :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
            :           : :           : :           :
            :  0.  0.  0.: :  0.  3.  4.: :  0.  0.  0.:
            :           : :           : :           :
            ------------- ------------- -------------
```

INCREASE NUMBER OF CYCLES ON LEVEL 1 TO   40.00

4.3.1.2 Planning a Stress Screen Program to Achieve a Certain MTBF, with Pre-established Screens. In this example the user is constrained to apply a pre-established screen (perhaps required by contract) at the Unit level. The SSM determines the minimum number of thermal cycles necessary to achieve the desired MTBF.

```
******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

    IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

    OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
     RELIABILITY REQUIREMENT

    OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

    OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS


    DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
    ENTER ZERO)
?
900

    TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
5000

    FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
     PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

```
IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION



ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
3
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
4

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER G LEVEL AND TIME IN MINUTES
?
6 7.5

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER G LEVEL AND TIME IN MINUTES
?
0 60

TEST STRENGTH FOR GIVEN SCREEN= 0.4658


PARAMETER FOR DESIRED VIBRATION SCREEN=       5.8




IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
0

    IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
     IF NOT, ENTER ZERO:
?
0
READY
```

********LEVEL 2********

```
    TEMPERATURE CYCLING, LEVEL 2
    THE DEFAULT VALUES ARE:
    LOWER TEMP=-54 DEG C
    UPPER TEMP=71 DEG C
    TEMP. RATE OF CHANGE=5 DEG C/MIN
    RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
    IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    UPPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO. OF CYCLES:
    (TEMPERATURE RANGE MUST BE WITHIN -55 TO +75 DEG C
    AND RATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)
?
75 -40 5 24

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
10000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
.002
```

```
********TEST AND PARAMETER SELECTION********


FOLLOWING  ARE THE AVAILABLE SCREENS :

1.  CONSTANT TEMPERATURE
2.  CYCLED TEMPERATURE
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION


DEFAULTS ARE:
     LEVEL 1          LEVEL 2          LEVEL 3
 TEMP. CYCLING       RAN.VIB       CONST. TEMP.
      (2)              (3)             (1)


    IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:
?
1


    ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING NUMBERS FROM ABOVE LISTING:
    IF YOU DO NOT WISH TO SCREEN AT A PARTICULAR LEVEL, ENTER ZERO:
FOR LEVEL 1 THE SCREEN NUMBER DESIRED IS:
?
0
FOR LEVEL 2 THE SCREEN NUMBER DESIRED IS:
?
2
FOR LEVEL 3 THE SCREEN NUMBER DESIRED IS:
?
0
```

T E S T   D E S C R I P T I O N

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						0.
TEST NO. 1		0.0	0.0	0.0	0.0	0.
LEVEL NO. 2						12071.
TEST NO. 2	CYT	75.00	-40.00	5.00	6.00	12071.
LEVEL NO. 3						0.
TEST NO. 1		0.0	0.0	0.0	0.0	0.
TOTAL COST					$	12071.

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS :	WORKMANSHIP 3.	4.	5.	6.	7.	8.	9.
0. :	1957.	1956.	1956.	1955.	1955.	1955.	1954.
1. :	1436.	1436.	1435.	1435.	1435.	1435.	1435.
2. :	1116.	1115.	1115.	1115.	1115.	1115.	1115.
3. :	912.	912.	912.	912.	912.	912.	912.
4. :	771.	771.	771.	771.	771.	771.	771.
5. :	668.	668.	668.	668.	668.	668.	668.
6. :	590.	590.	590.	590.	589.	589.	589.

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
5000	3	5.	0.0	900.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	0.
2	10.
3	0.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

```
INTERVAL MTBF

----------------
 TIME  :  MTBF
----------------
  2000. :   944.
  4000. :   976.
  6000. :  1007.
  8000. :  1037.
 10000. :  1066.
 12000. :  1094.
 14000. :  1122.
 16000. :  1148.
 18000. :  1174.
 20000. :  1199.


    IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
0
IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
 IF NOT ENTER ZERO:
?
0
READY
```

```
    IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
    IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
    ENTER ONE:
?
0
```

STRESS SCREENING FLOW DIAGRAM

```
-----------    -----------    -----------    -----------    -----------
: INCOMING :   : LEVEL 1  :   : LEVEL 2  :   : LEVEL 3  :   : OUTGOING :
-----------    -----------    -----------    -----------    -----------
:#PARTS:   :   :ADEF=     :   :ADEF=     :   :ADEF=     :   :DEF P REM::
:      5000:   :        0.:   :       10.:   :        0.:   :        3.:
:          :-->:          :-->:          :-->:          :-->:          :
:#DEFECTS: :   :TS=       :   :TS=       :   :TS=       :   :DEF U REM::
:        5.:   :      0.0 :   :     0.415:   :      0.0 :   :        6.:
:          :   :          :   :          :   :          :   :          :
:          :   :DEF PASSED:   :DEF PASSED:   :DEF PASSED:   :MTBF:     :
:          :   :        5.:   :        9.:   :        9.:   :      912.:
:          :   :          :   :          :   :          :   :          :
-----------    -----------    -----------    -----------    -----------
                    :              :              :
                    :              :              :
                    V              V              V
               -------------  -------------  -------------
               :           :  :           :  :           :
               : EXPECTED  :  : EXPECTED  :  : EXPECTED  :
               : FALLOUT:  :  : FALLOUT:  :  : FALLOUT:  :
               :           :  :           :  :           :
               : PRT UKN TOT: : PRT UKN TOT: : PRT UKN TOT:
               :  0.  0.  0.: :  2.  4.  6.: :  0.  0.  0.:
               :           :  :           :  :           :
               :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
               :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
               :           :  :           :  :           :
               :  0.  0.  0.: :  7. 11. 14.: :  0.  0.  0.:
               :           :  :           :  :           :
               :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
               :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
               :           :  :           :  :           :
               :  0.  0.  0.: :  0.  0.  0.: :  0.  0.  0.:
               :           :  :           :  :           :
               -------------  -------------  -------------
```

```
********TEST AND PARAMETER SELECTION********



    FOLLOWING  ARE THE AVAILABLE SCREENS :

    1.  CONSTANT TEMPERATURE
    2.  CYCLED TEMPERATURE
    3.  RANDOM VIBRATION
    4.  SINE SWEEP VIBRATION
    5.  SINE FIXED VIBRATION


    DEFAULTS ARE:
         LEVEL 1          LEVEL 2          LEVEL 3
     TEMP. CYCLING       RAN.VIB       CONST. TEMP.
          (2)              (3)              (1)


    IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:
?
0
```

4.3.1.3 Planning a Stress Screening Program to Achieve a Certain MTBF, No Solution. In this example, the desired MTBF cannot be achieved by stress screening alone. The SSM determines that maximum strength screens will not precipitate enough latent defects to achieve the desired MTBF. Other measures are required, such as reducing the incoming part fraction defective (by using higher quality grade parts or performing incoming receiving screening) or by reducing the workmanship defects induced at one or more stages. The SSM prints out the best possible solution for the conditions given.

```
******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

    IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

    OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
     RELIABILITY REQUIREMENT

    OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

    OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS


    DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
    ENTER ZERO)
?
1300

    TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
8000

    FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
     PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 2********

    RANDOM VIBRATION, LEVEL 2
    THE DEFAULT VALUES ARE:
    G-LEVEL=6 G
    RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
    IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    G LEVEL, TIME IN MIN:
    (G LEVEL MUST BE BETWEEN .6 AND 7.5)
?
6 40

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
0
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
*********LEVEL 1*********

    TEMPERATURE CYCLING, LEVEL 1
    THE DEFAULT VALUES ARE:
    LOWER TEMP=-54 DEG C
    UPPER TEMP=71 DEG C
    TEMP. RATE OF CHANGE=5 DEG C/MIN
    RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
    IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
0
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:

?

1

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CRESD	MTBF
8000	3	8.	0.0	1300.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	16.
2	8.
3	4.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

REQUIREMENT CANNOT BE MET

```
********LEVEL 3********

    CONSTANT TEMPERATURE, LEVEL 3
    THE DEFAULT VALUES ARE:
    TEMPERATURE=70 DEG C
    TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
    IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT,ENTER 1:
?
1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    TEMP IN DEG C, TIME IN HRS:
    (TEMP MUST BE LESS THAN +75 DEG C)
?
70 96

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
0
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

STRESS SCREENING FLOW DIAGRAM

```
------------  ------------  ------------  ------------  ------------
! INCOMING !  ! LEVEL 1  !  ! LEVEL 2  !  ! LEVEL 3  !  ! OUTGOING !
------------  ------------  ------------  ------------  ------------
!#PARTS:   !  !ADEF=     !  !ADEF=     !  !ADEF=     !  !DEF P REM:!
!      8000!  !       16.!  !        8.!  !        4.!  !        1.!
!          !-->!         !-->!         !-->!         !-->!         !
!#DEFECTS: !  !TS=       !  !TS=       !  !TS=       !  !DEF W REM:!
!        8.!  !     0.615!  !     0.683!  !     0.314!  !        6.!
!          !  !          !  !          !  !          !  !          !
!          !  !DEF PASSED!  !DEF PASSED!  !DEF PASSED!  !MTBF:     !
!          !  !        9.!  !        5.!  !        6.!  !     1051.!
!          !  !          !  !          !  !          !  !          !
------------  ------------  ------------  ------------  ------------
                    !             !             !
                    !             !             !
                    V             V             V
              ------------- ------------- -------------
              !           ! !           ! !           !
              ! EXPECTED  ! ! EXPECTED  ! ! EXPECTED  !
              ! FALLOUT:  ! ! FALLOUT:  ! ! FALLOUT:  !
              !           ! !           ! !           !
              ! PRT WKM TOT! ! PRT WKM TOT! ! PRT WKM TOT!
              !  4. 11. 15.! !  2. 10. 12.! !  0.  3.  3.!
              !           ! !           ! !           !
              !UPPR BND FOR! !UPPR BND FOR! !UPPR BND FOR!
              !OBS FALLOUT:! !OBS FALLOUT:! !OBS FALLOUT:!
              !           ! !           ! !           !
              ! 11. 21. 26.! !  7. 20. 22.! !  0.  9.  9.!
              !           ! !           ! !           !
              !LOWR BND FOR! !LOWR BND FOR! !LOWR BND FOR!
              !OBS FALLOUT:! !OBS FALLOUT:! !OBS FALLOUT:!
              !           ! !           ! !           !
              !  0.  2.  5.! !  0.  2.  3.! !  0.  0.  0.!
              !           ! !           ! !           !
              ------------- ------------- -------------
```

T E S T   D E S C R I P T I O N

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						1375.
TEST NO. 2	CYT	71.00	-54.00	5.00	20.00	1375.
LEVEL NO. 2						3557.
TEST NO. 3	RVIB	6.00	40.00	0.0	0.0	3557.
LEVEL NO. 3						5824.
TEST NO. 1	CT	70.00	96.00	0.0	0.0	5824.
TOTAL COST					$	10756.

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS :	WORKMANSHIP 3.	4.	5.	6.	7.	8.	9.
0. :	1223.	1223.	1223.	1223.	1223.	1222.	1222.
0. :	1223.	1223.	1223.	1223.	1223.	1222.	1222.
0. :	1223.	1223.	1223.	1223.	1223.	1222.	1222.
1. :	1051.	1051.	1051.	1051.	1051.	1051.	1050.
2. :	869.	869.	868.	868.	868.	868.	868.
3. :	740.	740.	740.	740.	740.	740.	740.
4. :	645.	645.	645.	645.	645.	645.	644.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:

?
0

```
    IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
0
IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
 IF NOT ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION



ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
1
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER ABSOLUTE VALUE OF DIFFERENCE BETWEEN TEMP IN DEG C AND 25 DEG C
 AND TIME IN HOURS
?
45 96

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 3 0

TEST STRENGTH FOR GIVEN SCREEN= 0.3143


PARAMETER IN DESIRED TEMP CYCLING SCREEN=      8.0
```

INTERVAL MTBF

TIME	MTBF
2000.	1054.
4000.	1057.
6000.	1060.
8000.	1063.
10000.	1065.
12000.	1068.
14000.	1071.
16000.	1073.
18000.	1076.
20000.	1078.

4.3.2 Cost Option Example

In this example, the user desires a set of screens which precipitate the maximum number of latent defects for a fixed dollar amount of $40,000.

```
        ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

    IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

    OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
     RELIABILITY REQUIREMENT

    OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

    OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS



    DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
    ENTER ZERO)
?
0

    COST BUDGET(OPTION B ONLY,FOR OPTION A OR C ENTER ZERO)
?
40000

    TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
7000

    FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
     PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

```
IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION


ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
2
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
125 5 20

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 3 0

TEST STRENGTH FOR GIVEN SCREEN= 0.6145

PARAMETER IN DESIRED TEMP CYCLING SCREEN=      61.6
```

```
                    ********LEVEL 1********

    TEMPERATURE CYCLING, LEVEL 1
    THE DEFAULT VALUES ARE:
    LOWER TEMP=-54 DEG C
    UPPER TEMP=71 DEG C
    TEMP. RATE OF CHANGE=5 DEG C/MIN
    RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
    IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
10000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
40
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

DEFAULTS ARE:

LEVEL 1	LEVEL 2	LEVEL 3
TEMP. CYCLING	RAN.VIB	CONST. TEMP.
(2)	(3)	(1)

IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:

?

0

```
        *********LEVEL 3*********

    CONSTANT TEMPERATURE, LEVEL 3
    THE DEFAULT VALUES ARE:
    TEMPERATURE=70 DEG C
    TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
    IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT,ENTER 1:
?
0

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
10000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
50
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
1000
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
*********LEVEL 2*********

    RANDOM VIBRATION, LEVEL 2
    THE DEFAULT VALUES ARE:
    G-LEVEL=6 G
    RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
    IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
10000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
50
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
500
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

TEST DESCRIPTION

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						11529.
TEST NO. 2	CYT	71.00	-54.00	5.00	20.00	11529.
LEVEL NO. 2						13090.
TEST NO. 3	RVIB	6.00	5.00	0.0	0.0	13090.
LEVEL NO. 3						15341.
TEST NO. 1	CT	70.00	48.00	0.0	0.0	15341.
TOTAL COST					$	39960.

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS	WORKMANSHIP 5.	6.	7.	8.	9.	10.	11.
0.	1397.	1397.	1397.	1397.	1397.	1396.	1396.
0.	1397.	1397.	1397.	1397.	1397.	1396.	1396.
0.	1317.	1317.	1317.	1317.	1317.	1317.	1316.
1.	1043.	1043.	1043.	1042.	1042.	1042.	1042.
2.	863.	863.	863.	863.	863.	863.	862.
3.	736.	736.	736.	736.	736.	736.	736.
4.	642.	642.	641.	641.	641.	641.	641.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:

?
1

ENTER PROBABILITY DESIRED:

?
.8

```
IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1
```

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
7000	3	7.	40000.00	0.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	14.
2	7.
3	4.

REWORK COST

LEVEL 1	45.
LEVEL 2	500.
LEVEL 3	1000.

INTERVAL MTBF

TIME	MTBF
2000.	1049.
4000.	1056.
6000.	1062.
8000.	1069.
10000.	1075.
12000.	1081.
14000.	1087.
16000.	1093.
18000.	1098.
20000.	1104.

```
    IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
 ?
 0
 IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
  IF NOT ENTER ZERO:
 ?
 0

   IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
    IF NOT, ENTER ZERO:
?
0
READY
```

STRESS SCREENING FLOW DIAGRAM

```
-----------   ------------   ------------   ------------   ------------
: INCOMING :   : LEVEL 1   :   : LEVEL 2   :   : LEVEL 3   :   : OUTGOING :
-----------   ------------   ------------   ------------   ------------
:#PARTS:   :   :ADEF=      :   :ADEF=      :   :ADEF=      :   :DEF P REM::
:     7000:   :        14.:   :         7.:   :         4.:   :        1.:
:          :-->:           :-->:           :-->:           :-->:          :
:#DEFECTS: :   :TS=        :   :TS=        :   :TS=        :   :DEF # REM::
:       7.:   :     0.615:   :     0.409:   :     0.237:   :        8.:
:          :   :           :   :           :   :           :   :          :
:          :   :DEF PASSED:   :DEF PASSED:   :DEF PASSED:   :MTBF:     :
:          :   :         8.:   :         9.:   :         9.:   :     1042.:
:          :   :           :   :           :   :           :   :          :
-----------   ------------   ------------   ------------   ------------
                     :              :              :
                     :              :              :
                     V              V              V
              -------------- -------------- --------------
              :            : :            : :            :
              :  EXPECTED  : :  EXPECTED  : :  EXPECTED  :
              :  FALLOUT:  : :  FALLOUT:  : :  FALLOUT:  :
              :            : :            : :            :
              : PRT UKN TOT: : PRT UKN TOT: : PRT UKN TOT:
              :  4.  9. 13.: :  1.  5.  6.: :  0.  3.  3.:
              :            : :            : :            :
              :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :            : :            : :            :
              :  8. 14. 18.: :  3.  9. 10.: :  0.  6.  6.:
              :            : :            : :            :
              :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :            : :            : :            :
              :  1.  4.  7.: :  0.  1.  2.: :  0.  0.  0.:
              :            : :            : :            :
              -------------- -------------- --------------
```

```
********TEST AND PARAMETER SELECTION********

    FOLLOWING  ARE THE AVAILABLE SCREENS :

    1.  CONSTANT TEMPERATURE
    2.  CYCLED TEMPERATURE
    3.  RANDOM VIBRATION
    4.  SINE SWEEP VIBRATION
    5.  SINE FIXED VIBRATION

    ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING NUMBERS FROM ABOVE LISTING:
    IF YOU DO NOT WISH TO SCREEN AT A PARTICULAR LEVEL, ENTER ZERO:
FOR LEVEL 1 THE SCREEN NUMBER DESIRED IS:
?
1
FOR LEVEL 2 THE SCREEN NUMBER DESIRED IS:
?
2
FOR LEVEL 3 THE SCREEN NUMBER DESIRED IS:
?
4
```

4.3.3 Tradeoff Option Examples

4.3.3.1 Evaluating an Existing Screen. The user has an existing screen and wishes to have the SSM determine the cost and test strength of that screen. After having evaluated an existing screen, the MTBF Option should be exercised to allow the SSM to determine an optimum screen to achieve the same MTBF. Alternatively, the Cost Option may be exercised to determine what MTBF is achievable for the same cost as the existing screen.

```
******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
 RELIABILITY REQUIREMENT

OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS


DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
ENTER ZERO)
?
0

COST BUDGET(OPTION B ONLY,FOR OPTION A OR C ENTER ZERO)
?
0

TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
5000

FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
 PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

```
                    ********LEVEL 2********

    TEMPERATURE CYCLING, LEVEL 2
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    UPPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO. OF CYCLES:
    (TEMPERATURE RANGE MUST BE WITHIN -55 TO +75 DEG C
    AND RATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)
?
70 -40 10 12

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
0
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 1********

    CONSTANT TEMPERATURE, LEVEL 1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    TEMP IN DEG C, TIME IN HRS:
    (TEMP MUST BE LESS THAN +75 DEG C)
?
70 96

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
0
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREBD	MTBF
5000	3	5.	NA	NA

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	10.
2	5.
3	3.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

T E S T   D E S C R I P T I O N

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						3092.
TEST NO. 1	CT	70.00	96.00	0.0	0.0	3092.
LEVEL NO. 2						3380.
TEST NO. 2	CYT	70.00	-40.00	10.00	12.00	3380.
LEVEL NO. 3						2751.
TEST NO. 4	SSVB	6.00	20.00	0.0	0.0	2751.
TOTAL COST					$	9223.

********LEVEL 3********

SINE SWEEP VIBRATION, LEVEL 3
ENTER IN ORDER, SEPARATED BY COMMAS OR SPACES:
G-LEVEL, TIME IN MIN:
(G LEVEL BETWEEN 0 AND 10)
?
6 20

ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

FIXED TEST COST IN DOLLARS=
?
0
VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0

IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1

STRESS SCREENING FLOW DIAGRAM

```
------------  ------------  ------------  ------------  ------------
| INCOMING |  | LEVEL 1  |  | LEVEL 2  |  | LEVEL 3  |  | OUTGOING |
------------  ------------  ------------  ------------  ------------
|#PARTS:   |  |ADEF=     |  |ADEF=     |  |ADEF=     |  |DEF P REM:|
|      5000|  |       10.|  |        5.|  |        3.|  |        1.|
|          |-->|         |-->|         |-->|         |-->|         |
|#DEFECTS: |  |TS=       |  |TS=       |  |TS=       |  |DEF U REM:|
|        5.|  |     0.314|  |     0.689|  |     0.381|  |        4.|
|          |  |          |  |          |  |          |  |          |
|          |  |DEF PASSED|  |DEF PASSED|  |DEF PASSED|  |MTBF:     |
|          |  |       10.|  |        5.|  |        4.|  |     1555.|
|          |  |          |  |          |  |          |  |          |
------------  ------------  ------------  ------------  ------------
                    |             |             |
                    |             |             |
                    V             V             V
              -------------- -------------- --------------
              |            | |            | |            |
              |  EXPECTED  | |  EXPECTED  | |  EXPECTED  |
              |  FALLOUT:  | |  FALLOUT:  | |  FALLOUT:  |
              |            | |            | |            |
              | PRT UKN TOT| | PRT UKN TOT| | PRT UKN TOT|
              |  1.  4.  5.| |  2.  9. 11.| |  0.  3.  3.|
              |            | |            | |            |
              |UPPR BND FOR| |UPPR BND FOR| |UPPR BND FOR|
              |OBS FALLOUT:| |OBS FALLOUT:| |OBS FALLOUT:|
              |            | |            | |            |
              |  5. 10. 12.| |  7. 18. 21.| |  0.  9.  9.|
              |            | |            | |            |
              |LOWR BND FOR| |LOWR BND FOR| |LOWR BND FOR|
              |OBS FALLOUT:| |OBS FALLOUT:| |OBS FALLOUT:|
              |            | |            | |            |
              |  0.  0.  0.| |  0.  1.  2.| |  0.  0.  0.|
              |            | |            | |            |
              -------------- -------------- --------------
```

INTERVAL MTBF

TIME	MTBF
2000.	1564.
4000.	1573.
6000.	1582.
8000.	1591.
10000.	1599.
12000.	1607.
14000.	1615.
16000.	1623.
18000.	1630.
20000.	1637.

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS :	WORKMANSHIP 1.	2.	3.	4.	5.	6.	7.
0. :	1957.	1957.	1957.	1956.	1956.	1955.	1955.
0. :	1957.	1957.	1957.	1956.	1956.	1955.	1955.
0. :	1957.	1957.	1957.	1956.	1956.	1955.	1955.
1. :	1556.	1555.	1555.	1555.	1555.	1554.	1554.
2. :	1187.	1186.	1186.	1186.	1186.	1186.	1186.
3. :	959.	959.	959.	959.	959.	959.	959.
4. :	805.	805.	805.	805.	805.	804.	804.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:

?
0

```
IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION



ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
2
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
110 10 12

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 5 0

TEST STRENGTH FOR GIVEN SCREEN= 0.6887


PARAMETER IN DESIRED TEMP CYCLING SCREEN=      43.8
```

```
   IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
0
IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
 IF NOT ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION


ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
1
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
2

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER ABSOLUTE VALUE OF DIFFERENCE BETWEEN TEMP IN DEG C AND 25 DEG C
 AND TIME IN HOURS
?
45 96

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER RANGE IN DEG C
 TEMP RATE OF CHANGE IN DEG C/MIN
 AND NUMBER OF CYCLES
?
100 5 0

TEST STRENGTH FOR GIVEN SCREEN= 0.3143


PARAMETER IN DESIRED TEMP CYCLING SCREEN=       3.4
```

```
IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1. CONSTANT TEMPERATURE
2. TEMPERATURE CYCLING
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION



ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
4
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
3

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER G LEVEL AND TIME IN MINUTES
?
6 20

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER G LEVEL AND TIME IN MINUTES
?
5 0

TEST STRENGTH FOR GIVEN SCREEN= 0.3814


PARAMETER FOR DESIRED VIBRATION SCREEN=       6.3




IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
0

 IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
  IF NOT, ENTER ZERO:
?
0
READY
```

```
IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE, IF NOT, ENTER ZERO:
?
1

FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:
1.  CONSTANT TEMPERATURE
2.  TEMPERATURE CYCLING
3.  RANDOM VIBRATION
4.  SINE SWEEP VIBRATION
5.  SINE FIXED VIBRATION


ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN SCREEN:
?
4
ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO DESIRED SCREEN:
?
3

ENTER PARAMETERS FOR GIVEN SCREEN:

ENTER G LEVEL AND TIME IN MINUTES
?
6 20

ENTER PARAMETERS FOR DESIRED SCREEN;
 ENTER ZERO FOR PARAMETER TO BE FOUND:

ENTER G LEVEL AND TIME IN MINUTES
?
0 15

TEST STRENGTH FOR GIVEN SCREEN= 0.3814
SOLUTION CANNOT BE FOUND BY INTERNAL METHOD.
 TRY A GRID OF POSSIBLE SOLUTIONS.
```

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING NUMBERS FROM ABOVE LISTING:
IF YOU DO NOT WISH TO SCREEN AT A PARTICULAR LEVEL, ENTER ZERO:

```
FOR LEVEL 1 THE SCREEN NUMBER DESIRED IS:
?
2
FOR LEVEL 2 THE SCREEN NUMBER DESIRED IS:
?
4
FOR LEVEL 3 THE SCREEN NUMBER DESIRED IS:
?
1
```

4.3.3.2 Adapting Screens Based on Observed Results. In this example, the user has actual screen data which falls outside the bounds of the selected probability interval. Note on the Stress Screening Flow Diagram at level 2 that the expected number of workmanship defects is 8, with an 80 percent probability interval of 3 to 12. The actual number of workmanship defects observed is 2 which is entered into the SSM. A new screening strength is computed (0.158) based on observed results and an increase in vibration time from 20 minutes to 60 minutes is recommended to achieve the desired screening strength.

```
          ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

    IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

    OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
     RELIABILITY REQUIREMENT

    OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

    OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS


    DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
    ENTER ZERO)
?
0

    COST BUDGET(OPTION B ONLY,FOR OPTION A OR C ENTER ZERO)
?
0

    TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
9000

    FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
     PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 2********

    SINE SWEEP VIBRATION, LEVEL 2
    ENTER IN ORDER, SEPARATED BY COMMAS OR SPACES:
    G-LEVEL, TIME IN MIN:
    (G LEVEL BETWEEN 0 AND 10)
?
6 20

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
20000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
50
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?

500
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 1********

    TEMPERATURE CYCLING, LEVEL 1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    UPPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO. OF CYCLES:
    (TEMPERATURE RANGE MUST BE WITHIN -55 TO +75 DEG C
    AND RATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)
?
70 -40 4 8

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
10000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
40
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
50
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
9000	3	9.	NA	NA

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	18.
2	9.
3	5.

REWORK COST

LEVEL 1	50.
LEVEL 2	500.
LEVEL 3	1000.

T E S T   D E S C R I P T I O N

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						10962.
TEST NO. 2	CYT	70.00	-40.00	4.00	8.00	10962.
LEVEL NO. 2						24856.
TEST NO. 4	SSVB	6.00	20.00	0.0	0.0	24856.
LEVEL NO. 3						37922.
TEST NO. 1	CT	75.00	40.00	0.0	0.0	37922.
TOTAL COST					$	73740.

********LEVEL 3********

```
    CONSTANT TEMPERATURE, LEVEL 3
    ENTER, IN ORDER, SEPARATED BY COMMAC OR SPACES:
    TEMP IN DEG C, TIME IN HRS:
    (TEMP MUST BE LESS THAN +75 DEG C)
?
75 48

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
30000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
60
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
1000
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0


    IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1
```

STRESS SCREENING FLOW DIAGRAM

```
------------   ------------   ------------   ------------   ------------
: INCOMING :   : LEVEL 1  :   : LEVEL 2  :   : LEVEL 3  :   : OUTGOING :
------------   ------------   ------------   ------------   ------------
:#PARTS:   :   :ADEF=     :   :ADEF=     :   :ADEF=     :   :DEF P REM::
:      9000:   :       18.:   :        9.:   :        5.:   :        3.:
:          :-->:          :-->:          :-->:          :-->:          :
:#DEFECTS: :   :TS=       :   :TS=       :   :TS=       :   :DEF W REM::
:        9.:   :     0.394:   :     0.381:   :     0.250:   :       13.:
:          :   :          :   :          :   :          :   :          :
:          :   :DEF PASSED:   :DEF PASSED:   :DEF PASSED:   :MTBF:     :
:          :   :       16.:   :       16.:   :       15.:   :      701.:
:          :   :          :   :          :   :          :   :          :
------------   ------------   ------------   ------------   ------------
                    :              :              :
                    :              :              :
                    V              V              V
              -------------- -------------- --------------
              :            : :            : :            :
              :  EXPECTED  : :  EXPECTED  : :  EXPECTED  :
              :  FALLOUT:  : :  FALLOUT:  : :  FALLOUT:  :
              :            : :            : :            :
              : PRT WKM TOT: : PRT WKM TOT: : PRT WKM TOT:
              :  3.  8. 11.: :  2.  8. 10.: :  0.  5.  5.:
              :            : :            : :            :
              :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :            : :            : :            :
              :  6. 12. 16.: :  5. 12. 15.: :  0.  9.  9.:
              :            : :            : :            :
              :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :            : :            : :            :
              :  0.  3.  6.: :  0.  3.  5.: :  0.  1.  1.:
              :            : :            : :            :
              -------------- -------------- --------------
```

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS :	WORKMANSHIP 10.	11.	12.	13.	14.	15.	16.
0. :	1086.	1086.	1086.	1086.	1086.	1086.	1086.
1. :	974.	974.	974.	973.	973.	973.	973.
2. :	815.	815.	815.	815.	815.	815.	815.
3. :	701.	701.	701.	701.	701.	701.	701.
4. :	615.	615.	615.	615.	615.	615.	615.
5. :	547.	547.	547.	547.	547.	547.	547.
6. :	493.	493.	493.	493.	493.	493.	493.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
1
ENTER PROBABILITY DESIRED:
?
.8

STRESS SCREENING RESULTS:

```
 ------------   ------------   ------------   ------------   ------------
 ! INCOMING !   ! LEVEL 1  !   ! LEVEL 2  !   ! LEVEL 3  !   ! OUTGOING !
 ------------   ------------   ------------   ------------   ------------
 !#PARTS:   !   !ADEF=     !   !ADEF=     !   !ADEF=     !   !DEF P REM:!
 !      9000!   !       18.!   !        9.!   !        5.!   !        5.!
 !          !-->!          !-->!          !-->!          !-->!          !
 !#DEFECTS: !   !TS=       !   !TS=       !   !TS=       !   !DEF U REM:!
 !        9.!   !     0.394!   !     0.158!   !     0.250!   !       14.!
 !          !   !          !   !          !   !          !   !          !
 !          !   !DEF PASSED!   !DEF PASSED!   !DEF PASSED!   !MTBF:     !
 !          !   !       16.!   !       21.!   !       19.!   !      521.!
 !          !   !          !   !          !   !          !   !          !
 ------------   ------------   ------------   ------------   ------------
                      !              !              !
                      !              !              !
                      V              V              V
                -------------- -------------- --------------
                !            ! !            ! !            !
                !  EXPECTED  ! !  EXPECTED  ! !  EXPECTED  !
                !  FALLOUT:  ! !  FALLOUT:  ! !  FALLOUT:  !
                !            ! !            ! !            !
                ! PRT UKN TOT! ! PRT UKN TOT! ! PRT UKN TOT!
                !  3.  8. 11.! !  0.  4.  4.! !  1.  6.  7.!
                !            ! !            ! !            !
                !UPPR BND FOR! !UPPR BND FOR! !UPPR BND FOR!
                !OBS FALLOUT:! !OBS FALLOUT:! !OBS FALLOUT:!
                !            ! !            ! !            !
                !  6. 12. 16.! !  0.  8.  8.! !  3.  9. 11.!
                !            ! !            ! !            !
                !LOWR BND FOR! !LOWR BND FOR! !LOWR BND FOR!
                !OBS FALLOUT:! !OBS FALLOUT:! !OBS FALLOUT:!
                !            ! !            ! !            !
                !  0.  3.  6.! !  0.  1.  1.! !  0.  2.  2.!
                !            ! !            ! !            !
                -------------- -------------- --------------

     INCREASE TIME ON LEVEL 2 TO      60.00 MINUTES


   IF YOU WISH TO ANALYZE EQUIVALENT SCREENS  ENTER ONE
    IF NOT ENTER ZERO:
   ?
   0


    IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
     IF NOT, ENTER ZERO:
?
0
READY
```

```
                    INTERVAL MTBF

                  -----------------
                    TIME  !  MTBF
                  -----------------
                    2000. !   709.
                    4000. !   717.
                    6000. !   725.
                    8000. !   733.
                   10000. !   740.
                   12000. !   748.
                   14000. !   755.
                   16000. !   762.
                   18000. !   769.
                   20000. !   776.


   IF YOU HAVE FALLOUT DATA ENTER 1, IF NOT ENTER ZERO:
?
1
   IF YOU HAVE SEPARATE FALLOUT FOR PARTS AND WORKMANSHIP ENTER ONE
   IF YOU HAVE TOTAL FALLOUT ONLY AT EACH LEVEL, ENTER ZERO:
?
1
   ENTER, IN ORDER, ACTUAL FALLOUT:
   DUE TO    (A) PARTS    (B) WORKMANSHIP, AS PROMPTED:
   FOR LEVEL 1:
?
3 7
   FOR LEVEL 2:
?
2 2
   FOR LEVEL 3:
?
0 6
```

********TEST AND PARAMETER SELECTION********

FOLLOWING ARE THE AVAILABLE SCREENS :

1. CONSTANT TEMPERATURE
2. CYCLED TEMPERATURE
3. RANDOM VIBRATION
4. SINE SWEEP VIBRATION
5. SINE FIXED VIBRATION

DEFAULTS ARE:

LEVEL 1	LEVEL 2	LEVEL 3
TEMP. CYCLING	RAN.VIB	CONST. TEMP.
(2)	(3)	(1)

IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT, ENTER 1:

?
0

4.3.4 Example Using the CDE Model to Evaluate Screening Results.

In this example, three levels of screens are used, based on model defaults. The stress screening flow diagram shows an expected fallout of 13 defects at Level 3. The user actually experienced 16 defects and also had times-to-failure for each defect. In this example, the times-to-failure are entered into the SSM and the CDE model is fit to the failure distribution, resulting in estimates for the number of defects entering the Level 3 screen and the screening strength at that level. In this example, the estimated number of defects is unchanged, (33), but the screening strength estimate is revised upward to 0.521 from 0.382.

```
EX SSM



        ******** SELECTION OF PROGRAM INPUTS AND OPTIONS ********

 IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:

 OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A GIVEN PRODUCT
  RELIABILITY REQUIREMENT

 OPTION B OPTIMIZES PRODUCT RELIABILITY GIVEN A FIXED COST

 OPTION C COMPUTES TEST STRENGTHS OF EXISTING SCREENS



 DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ONLY,FOR OPTIONS B OR C
 ENTER ZERO)
?
600

 TOTAL PART POPULATION(NO DEFAULT AVAILABLE)
?
20000

 FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=
?
0 0
  PART QUALITY DEFECTS AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 2********

    RANDOM VIBRATION, LEVEL 2
    THE DEFAULT VALUES ARE:
    G-LEVEL=6 G
    RANGE OF TIME TO BE INVESTIGATED=0 TO 10 MIN.
    IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 2

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
30000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

```
********LEVEL 1********

    TEMPERATURE CYCLING, LEVEL 1
    THE DEFAULT VALUES ARE:
    LOWER TEMP=-54 DEG C
    UPPER TEMP=71 DEG C
    TEMP. RATE OF CHANGE=5 DEG C/MIN
    RANGE OF CYCLES TO BE INVESTIGATED=0 TO 20
    IF YOU WISH THE DEFAULT VALUES ENTER ZERO, IF NOT, ENTER 1:
?
0

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 1

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
20000
    VARIABLE TEST COST IN DOLLARS PER HOUR=
?
0
    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?
0
```

PROGRAM DATA

NPARTS	LEVELS	(PDEF X NPARTS)	CREQD	MTBF
20000	3	20.	0.0	600.

ASSEMBLY DATA

ASSEMBLY LEVEL	EXPECTED NUMBER OF ASSEMBLY DEFECTS
1	40.
2	20.
3	10.

REWORK COST

LEVEL 1	45.
LEVEL 2	300.
LEVEL 3	990.

REQUIREMENT CANNOT BE MET
MTBF POSSIBLE= 462.9
MTBF REQUIRED= 600.0

```
                    ********LEVEL 3********

    CONSTANT TEMPERATURE, LEVEL 3
    THE DEFAULT VALUES ARE:
    TEMPERATURE=70 DEG C
    TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS
    IF YOU WISH THE DEFAULT VALUES, ENTER ZERO, IF NOT,ENTER 1:
?
1
    ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:
    TEMP IN DEG C, TIME IN HRS:
    (TEMP MUST BE LESS THAN +75 DEG C)
?
70 160

    ENTER THE FOLLOWING MANUFACTURING PROCESS DATA, LEVEL 3

    IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZERO:

    FIXED TEST COST IN DOLLARS=
?
0
    VARIABLE TEST COST IN DOLLARS PER HOUR=
0

    AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT DETECTED AT THIS LEVEL=
?
0
    ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION OF TOTAL PARTS=
?

?
0


    IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT, ENTER ZERO:
?
1
```

INSTANTANEOUS MTBF FOR REMAINING
FLAWS AT END OF SCREENING

PARTS :	WORKMANSHIP 15.	16.	17.	18.	19.	20.	21.
0. :	489.	489.	489.	489.	489.	489.	489.
0. :	489.	489.	489.	489.	489.	489.	489.
1. :	446.	445.	445.	445.	445.	445.	445.
2. :	409.	409.	409.	409.	409.	409.	409.
3. :	378.	378.	378.	378.	378.	378.	378.
4. :	352.	352.	352.	352.	352.	352.	352.
5. :	328.	328.	328.	328.	328.	328.	328.

IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER ZERO
IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR A NARROWER INTERVAL)
ENTER ONE:
?
0

TEST SEQUENCE	TYPE	PARAMETER VALUE NO. 1	NO. 2	NO. 3	NO. 4	TOTAL COST($)
LEVEL NO. 1						22371.
TEST NO. 2	CYT	71.00	-54.00	5.00	20.00	22371.
LEVEL NO. 2						36031.
TEST NO. 3	RVIB	6.00	7.50	0.0	0.0	36031.
LEVEL NO. 3						17283.
TEST NO. 1	CT	70.00	160.00	0.0	0.0	17283.
TOTAL COST					$	75684.

INTERVAL MTBF

TIME	MTBF
2000.	393.
4000.	395.
6000.	397.
8000.	399.
10000.	401.
12000.	403.
14000.	404.
16000.	406.
18000.	407.
20000.	409.

STRESS SCREENING FLOW DIAGRAM

```
------------   ------------   ------------   ------------   ------------
: INCOMING :   : LEVEL 1  :   : LEVEL 2  :   : LEVEL 3  :   : OUTGOING :
------------   ------------   ------------   ------------   ------------
:#PARTS:   :   :ADEF=     :   :ADEF=     :   :ADEF=     :   :DEF P REM::
:    20000:   :       40.:   :       20.:   :       10.:   :        3.:
:          :-->:          :-->:          :-->:          :-->:          :
:#DEFECTS: :   :TS=       :   :TS=       :   :TS=       :   :DEF U REM::
:       20.:   :    0.615:   :    0.466:   :    0.382:   :       18.:
:          :   :          :   :          :   :          :   :          :
:          :   :DEF PASSED:   :DEF PASSED:   :DEF PASSED:   :MTBF:     :
:          :   :       23.:   :       23.:   :       20.:   :      392.:
:          :   :          :   :          :   :          :   :          :
------------   ------------   ------------   ------------   ------------
                    :              :              :
                    :              :              :
                    V              V              V
              -------------- -------------- --------------
              :            : :            : :            :
              :  EXPECTED  : :  EXPECTED  : :  EXPECTED  :
              :  FALLOUT:  : :  FALLOUT:  : :  FALLOUT:  :
              :            : :            : :            :
              : PRT UKM TOT: : PRT UKM TOT: : PRT UKM TOT:
              : 12. 25. 37.: :  3. 17. 20.: :  1. 12. 13.:
              :            : :            : :            :
              :UPPR BND FOR: :UPPR BND FOR: :UPPR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :            : :            : :            :
              : 23. 40. 55.: :  9. 30. 33.: :  5. 22. 24.:
              :            : :            : :            :
              :LOWR BND FOR: :LOWR BND FOR: :LOWR BND FOR:
              :OBS FALLOUT:: :OBS FALLOUT:: :OBS FALLOUT::
              :            : :            : :            :
              :  3. 12. 21.: :  0.  6.  9.: :  0.  3.  4.:
              :            : :            : :            :
              -------------- -------------- --------------
```

REFERENCES

1. R. E. Schafer, L. E. James, et al. "Electronic Equipment Screening and Debugging Techniques", Hughes Aircraft Company, Ground Systems Group, Fullerton, CA., RADC-TR-78-55, March 1978. AD# A053 561.

2. C. M. Ryerson, "Summary of Math Models for Reliability Screening and Related Product Assurance", Hughes Aircraft Company, Culver City, CA., Report No. FR-80-04-636, February 1980.

3. C. M. Ryerson, "Principles of Screening and Cost Effective Product Assurance", Hughes Aircraft Company, El Segundo, CA., Report No. FR-79-04-1191, November 1979.

4. C. M. Ryerson, "Reliability CREDIT", Hughes Aircraft Company, Culver City, CA., Report No. TIC 20-42-732, May 1973.

5. D. Edgerton Jr., "Stress Screening Studies", Hughes Aircraft Company, Canoga Park, CA., Report No. TIC 5150.76/501, June 1976.

6. R. L. Baker, T. Drnas, "Stress Screening Experiment, Phase One", Hughes Aircraft Company, Culver City, CA., Report No. P76-385, October 1976.

7. R. W. Burrows, "Long Life Assurance Study for Manned Spacecraft Long Life Hardware", Vols. 1-5, Martin Marietta Corporation, Denver, Colorado, December 1972.

8. F. Kube, G. Hirschberger, "An Investigation to Determine Effective Equipment Environmental Acceptance Test Methods", Grumman Aerospace Corporation, Report No., ADR 14-04-73.2, April 1973.

9. "Navy Manufacturing Screening Program", NAVMAT P-9492, May 1979.

```
    IF YOU HAVE FALLOUT NUMBERS ENTER 1, IF NOT, ENTER ZERO:
?
0

    IF YOU WISH TO ANALYZE EQUIVALENT SCREENS ENTER  ONE
     IF NOT, ENTER ZERO:
?
0

    IF YOU HAVE TIMES TO FAILURE FOR LEVEL III ENTER 1,
     IF NOT, ENTER ZERO:
?
1
    ENTER NUMBER OF FAILURES DURING FINAL SCREEN:
?
16
    ENTER FAILURE TIMES (HOURS), IN ORDER, AS PROMPTED:
?
8
?
14
?
20
?
27
?
34
?
41
?
54
?
61
?
68
?
77
?
86
?
96
?
107
?
118
?
129
?
141
    THE FAILURE TIMES INDICATE THAT THE ESTIMATED NUMBER
     OF DEFECTIVES ENTERING THE SCREEN IS        33.
     AND THE ESTIMATED SCREENING STRENGTH IS 0.521.
READY
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20. W. Silver, "Proposed Recommended Practices in Applying Broadband Vibration Screening to Electronic Hardware", Westinghouse Electric Corporation, Baltimore, Md., The Journal of Environmental Sciences, pp. 9-11, Jan.-Feb. 1981.

21. A. Bezat, L. Montague, "The Effect of Endless Burn-in on Reliability Growth Projections", Proceedings of the 1979 Annual Reliability and Maintainability Symposium, pp. 392-397.

22. K. W. Fertig, V. K. Murthy, "Models for Reliability Growth During Burn-in: Theory and Applications", Proceedings of the 1973 annual Reliability and Maintainability Symposium, pp. 504-509.

10. C. M. Ryerson, "Relating Factory Test Failure Results to Field Reliability, Required Field Maintenance, and to Total Life Cycle Costs", Hughes Aircraft Company, Culver City, CA., Report No. TIC 72-05, June 1972.

11. J. R. Anderson, "Environmental Burn-in Effectiveness", McDonnell Aircraft Company, St. Louis, Mo., Report No. AFWAL TR-80-3086, August 1980.

12. "Environmental Stress Screening Guidelines", The Institute of Environmental Sciences, Library of Congress", Catalog Card No. 62-38584, 1981.

13. L. E. James et al, "Microcircuit Cost Factors", Hughes Aircraft Company, Fullerton, CA., Report No. FR 81-16-326, February 1981.

14. "Optimum Burn-in Determination", Tracor Sciences and Systems, Arlington, VA., Document No. 9229, November 1979.

15. P. L. Shove, "The Effect of Screening and Burn-in on Electronic Reliability", Admiralty Surface Weapons Establishment (UK), Report No. TR-72-46, (AD915959), November 1972.

16. C. S. Murphy, "A Guide-line Document for Early Life Failure Screening Procedures on GW Equipment", Sperry Gyroscope (UK), Report No. TR 591, September 1977.

17. C. M. Ryerson, "Principles of Manufacturing Data Management", Hughes Aircraft Company, Report No. FR 81-01-812, May 1981.

18. C. M. Ryerson, "Card Level Acceptance Testing", Hughes Aircraft Co., Paper presented at 6th Aerospace Testing Seminar, Los Angeles, March 1981.

19. K. L. Wong, "Unified Field (Failure) Theory-Demise of the Bathtub Curve", Hughes Aircraft Company, Proceedings of the 1981 Annual Reliability and Maintainability Symposium, pp. 402-406.

The values shown in Table A.2 were obtained.

Table A.2 Screening Strength Constants for Data Taken from Raw Data.

	Constant		
G Level	B	C	D
1	6.006	.500	.201
2	4.004	.500	.401
3	3.003	.770	.401
4	2.279	.268	.720
5	4.004	.500	.801
6	2.697	.551	.751

A.1.3 <u>Single Model Based on Averaged Table Data</u>. Since C = .500 occurred frequently, SAS NLIN programs were run with C fixed at .500. The resulting B and D values were nearly linear as functions of g. The lines

$$B = -.375\ g + 5.047$$

$$D = .0863\ g + .273$$

were fitted by use of SAS.

A.1.4 <u>First Model Based on Weighted Averages of Table Data</u>. In the Grumman tests there were 19 detectable type I faults and 12 detectable type II faults. It was therefore decided to weight the averages of the individual percents of detected faults by using factors of 19/31 and 12/31, respectively.

Since the graph of time versus screening strength for 5 g vibration level was somewhat different in shape than the graphs for other g levels and since 1g and 2g are relatively low, the values were found for 3, 4, and 6 g.

APPENDIX A

DEVELOPMENT OF SCREENING STRENGTH EQUATIONS

A.1 Screening Strength Model for Random Vibration. Below are the steps used to obtain a single model for the screening strength of random vibration tests. Report ADR 14-04-73.2 by the Grumman Aerospace Corporation (Grumman Report, Ref. 8) supplied the raw data for the model.

A.1.1 Models Fitted to Data Taken from Graphs in Grumman Report. First, approximately fifteen ordered pairs (t, SS) were read for each of the 4 and 6 g vibration levels from the graphs. Type I and type II faults were averaged within each g level. The two resultant curves were analyzed and a model of the form

$$SS = D\,(1 - \exp\,(-t^{C}/B)).$$

B, C, D constants

was chosen for further analysis. The SAS NLIN program was used to find the best values of B, C, and D. The following constants were obtained and very good fit was exhibited.

Table A.1. Screening Strength Constants for Data Taken from Graphs.

Constant	G-Level 4g	6g
B	6.557	5.302
C	.935	.806
D	.496	.728

A.1.2 Models Fitted to Data Taken from Tables and Averaged. Since the Grumman report did not indicate how the screening strength curves were obtained from the raw data it was decided to fit a model to the data from Tables 6 and 7. Due to randomness, some of this data was not increasing with g. Wherever this occurred, an average failure value was used for both g levels. Also, the average values 2.5, 7.5, 17.5, and 42.5 were taken for t, time.

Again, SAS NLIN was used for fitting

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was monotone increasing with g.

A.1.5 Final Model Based on Weighted Averages of Table Data. Due to experience with the nonweighted averages, C was fixed at .500 and SAS NLIN was used to find the best corresponding values of B and D for 3, 4, and 6 g. As before, these values were nearly linear as functions of g. The lines

$$B = .266\ g + 1.402$$

$$D = .144\ g - .0862$$

were fitted using SAS.

Table A.5 Comparison of Single Model with Weighted Average Table Data.

g level	Time, In Minutes			
	2.5	7.5	17.5	42.5
3	#1. .177 #2. .210	.246 .226	.294 .278	.328 .355
4	#1. .232 #2. .258	.328 .307	.400 .387	.455 .452
6	#1. .319 #2. .307	.466 .452	.585 .613	.689 .677

#1. Model value.
#2. Weighted average of table data.

A.2 Screening Strength Model for Swept Sine Vibration. Data was obtained from tables 3 and 4 of the Grumman Report. Since there were 19 detectable type I faults and 20 detectable type II faults, a weighted average was used for screening strength at each value of g and t. Average times were also taken. This averaged table data follows in Table A.7 where it is compared to screening strength values from the models for individual g levels and the single model which has parameters time (t) and g levels.

The values for constants for B, C, and D were computed with SAS NLIN when SS was fitted to the table data for swept sine. They were used for computation of the individual model data in Table A.7 Constant values are shown in Table A.8.

Following are comparisons of this model with the averaged table data.

Table A.3. Comparison of Single Model with Table Data.

g level	Time, in minutes			
	2.5	7.5	17.5	42.5
1	#1: .103 #2: .042	.159 .042	.213 .084	.270 .167
2	#1: .137 #2: .167	.210 .250	.277 .250	.348 .292
3	#1: .177 #2: .271	.267 .292	.349 .355	.431 .428
4	#1: .222 #2: .311	.333 .375	.428 .445	.520 .501
5	#1: .277 #2: .311	.407 .375	.516 .465	.614 .627
6	#1: .342 #2: .350	.494 .493	.614 .638	.714 .706

#1: $SS = D\ (1 - \exp\ (-t^C/B))$
#2: averaged table data.

Table A.4. Screening Strength Constants for Data from Tables Using Weighted Average.

	Constant		
g level	B	C	D
3	3.003	.500	.401
4	2.536	.240	.711
6	3.244	.621	.712

$SS = D\ (1 - \exp\ (-t^C/B))$

Parabolas were fitted through the B and C values as functions of g level. A half parabola was estimated through the D values. This approach did not yield an SS model which

Table A.7 Comparison of Table Data with Single and Individual Models.

		Time, in minutes			
g level		2.5	7.5	17.5	42.5
1.5	Table	.0	.077	.180	.231
	Single Model	.051	.102	.151	.190
	Individual Model	.057	.113	.167	.208
3.0	Table	.077	.128	.205	.256
	Single Model	.075	.150	.222	.280
	Individual Model	.068	.136	.203	.256
5.0	Table	.103	.205	.359	.538
	Single Model	.107	.213	.317	.398
	Individual Model	.178	.356	.530	.668
10.0	Table	.154	.385	.564	.692
	Single Model	.185	.370	.551	.695
	Individual Model	.186	.372	.554	.698

Single Model:

$$SS = D\ (1 - \exp\ (-t^C/B)$$

$$C = .800$$

$$B(g) = .0176\ g + 7.097$$

$$D(g) = .0635\ g + .1065$$

"Compute.fort" was run to compare the resulting single model to individual model and table data. See Table A.7.

Table A.6 Comparisons of Single Model with Models Fitted for Individual g Levels.

g level	Time, In Minutes					
	10	15	20	30	40	50
3	#1: .261	.291	.311	.336	.352	.363
	#2: .264	.286	.301	.317	.322	.332
4	#1: .353	.377	.395	.420	.438	.452
	#2: .354	.378	.410	.437	.445	.462
6	#1: .516	.576	.614	.656	.678	.691
	#2: .507	.564	.603	.652	.670	.704

#1: Models fitted for each g level.
#2: Single model:

Note that the values on the charts correspond closely and that the single model exhibits other desired properties. SS is monotone increasing in t and $0<D<1$, $t>o$, $C>0$, $B>0$.

But $0<D<1$ for $.6 \leq g \leq 7.5$. $(.5986..< g < 7.543...)$ and $B>0$ for $g>0$.

The final screening strength model is,

$$SS = D\ (1 - \exp\ (t^{.5}/B)),\ t>0$$

$$B = .266\ g + 1.402,\ 0.6<g<7.5$$

$$D = .144\ g - .0862$$

Due to experience with other SS functions, C was fixed at .8 and SAS NLIN was run again. See Table A.9

It appeared that the 5 g constants were aberrant so lines were fitted to the remaining values of B and D as functions of g. These were

$$B(g) = .0176\ g + 7.097$$

$$D(g) = .0635\ g + .1065$$

A.3 <u>Screening Strength Model for Sine Fixed Frequency Vibration</u>. Raw data was obtained from Table 5 and Figure 9 of the Grumman Report. In the case where table data exhibited non-monotonicity (reversals) in g, the average was taken and used for both values. There were 19 detectable type I faults and 20 detectable type II faults so a weighted average was used. Average times were also taken. This averaged table data follows in Table A.10 where it is compared to screening strength values from the single model for various g levels and the models for individual g levels.

Table A.10 Comparison of Table Data, Single Model, and Individual Models for Sine Fixed Frequency.

		Time, Minutes			
g level		2.5	7.5	17.5	42.5
1.5	Table	.0	.0	.0	.0
	Single Model	.054	.066	.077	.090
3.0	Table	.0	.051	.103	.103
	Single Model	.068	.084	.097	.113
	Individual Model	.051	.063	.073	.086
5.0	Table	.128	.154	.154	.154
	Single Model	.091	.111	.129	.150
	Individual Model	.109	.133	.154	.179
5.6	Table	.154	.205	.231	.231
	Single Model	.112	.136	.157	.183
	Individual Model	.156	.187	.215	.247
10.0	Table	.154	.179	.256	.282
	Single Model	.180	.217	.250	.288
	Individual Model	.171	.207	.240	.276
12.0	Table	.230	.230	.286	.336
	Single Model	.240	.288	.329	.376
	Individual Model	.208	.250	.287	.329

Single Model:

$$SS = D\ (1 - \exp\ (-t^C/B)$$

$$B = -\ .4187g + 8.620$$

$$D = .04354g + .3235 \qquad C = .200$$

Table A.8 Values for Constants for Individual Models at Four g-Levels.

g Level	B	C	D
1.5	7.007	.800	.221
3.0	8.809	.600	.401
5.0	14.242	.789	.727
10.0	9.064	.954	.703

Table A.9 Constants for B and D with Fixed at .800:

g	B	D
1.5	7.007	.221
3.0	7.2917	.2734
5.0	14.253	.7127
10.0	7.248	.745

The single model

$$SS = D\ (1 - \exp(-t^{C}/B)$$

$$C = .800$$

$$B = .0176\ g + 7.097$$

$$D = .0635\ g + .1065$$

was selected for $0 < t < 60.0$ and $0 < g < 12.0$.

SS is monotone increasing in t for positive B, C, and D. C is always positive. B and D are positive for positive g. Also, $0 < D < 1$ for $g < 12.0$.

Lines were fitted through B and D as functions of g. They are:

$$B = .4187g \_ 8.620$$

$$D - .04354g + .3235$$

The single model for sine fixed frequency,

$$SS - D\ (1 - \exp\ (-t^C/B)$$

$$C = .200$$

$$B = .419g + 8.620$$

$$D = .0435g + .324$$

$t > 0$ and $0 < g < 15.5$ was selected. SS is monotone increasing in t for positive B, C, and D. C is always positive. D is positive for positive g. B is positive for 0 g 15.5. B is monotone decreasing in g so $1 - \exp\ (-t^C/B)$ is monotone increasing in g. Thus, with D also increasing in g, SS is increasing in g. Also, $0 < D < 1$ for $0 < g < 15.5$.

A.4 <u>Screening Strength Models for Temperature Screens.</u> Following is a description of the method used to obtain the screening strength equations for temperature screens. The temperature equation is an adaptation of it.

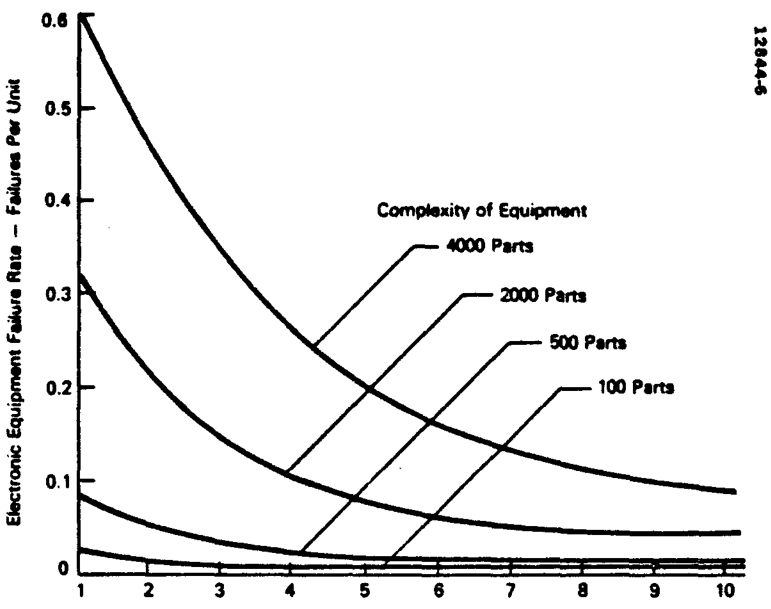

Figure A-1. Cycles as a Function of Equipment Complexity (Ref NAVMAT P-9492)

The values for constants for B, C, and D were computed by SAS NLIN when SS was fitted to the table data. The values are shown in Table A.11. They were used for the computation of the individual model data on Table A.10.

Table A.11. Values for Constants for Individual Models at Five g-Levels.

g level	B	C	D
3.0	7.007	.440	.201
5.0	6.006	.200	.601
6.5	4.004	.200	.601
10.0	5.005	.200	.801
12.0	4.004	.200	.801

Since C = .200 occurred frequently, C was fixed at .200 and the program run again on the 3g data. Fixing C at .200 yielded the constants

$$B = 8.800 \text{ and } D = .401$$

for the 3g individual model. Thus for C = .200 the constants are:

Table A.12. Values for B and D with C Fixed at 0.200.

g	B	D
3.0	8.800	.401
5.0	6.006	.601
6.5	4.004	.601
10.0	5.005	.801
12.0	4.004	.801

C/minute or less and temperature extremes within -55 deg. C to + 75 deg. C.

Only slight modifications are necessary to adapt the SS equation for temperature cycling to constant temperature. For constant temperature DT becomes 1.0 and Ncy = 0.0. Replacing Ncy is T = (time in hours) also to the 0.5 power. The range is computed from 25 deg. C.

The revised model gives reasonable solutions for its wide range of valid input parameters, exhibits consistency for constant temperature and temperature cycling, and is of the same general form as previously accepted test strength equations without exhibiting their inconsistencies. Figures 1.5 and 1.6 show the screening strengths for the temperature equations.

For the initial analysis, data was obtained from the temperature cycling curves of NAVMAT P-9492, shown above as Figure A.1. Comparisons of areas under the curves, reductions of failure rates, and other forms of analysis were used to obtain data points. The widely used 5 deg. C/minute rate of temperature change and 100 deg. C temperature range were assumed.

An exponential function was fit to the data. However, examination of a grid of screening strength values computed using this equation for typical ranges of the input parameters indicated that the computed screening strengths were higher than generally accepted test strengths.

Following extensive analysis, a set of subjective, but widely acceptable, screening strength values was fixed for 10 deg. C to 110 deg. C, range from 2 to 18 deg. C/minute temperature rate of change, and 5, 10, and 20 cycles. Curves were sketched through the set of points and additional data points were read from the graph. An equation which closely fit these data points and exhibits other desired properties follows:

$$SS = D\left(1.0 - \exp\left(-0.0023 \times (\mathrm{Ln}(e + DT))^{2.7} \times Ncy^{.5} \times R^{.6}\right)\right) \quad \text{(A-1)}$$

D = 0.85

DT = temperature rate of change (deg. C/min)

$1 < DT < 20$ (see below)

Ncy = number of repeated cycles

R = temperature range (deg. C) = high temperature - low temperature

high temperature $<$ 75 deg. C; low temperature $>$ -55 deg. C

SS = screening strength

Examination of a grid of screening test strength points computed using the above equation revealed reasonable values for reasonable values of the input parameters.

Since extremely low rates of change do not yield real temperature cycling stress, the equation is not to be used for DT less than 1 deg. C/min. If low rates of change for screening strength should be computed use the modifications for constant temperature given below.

Also, the data considered did not include extremely high rates of change or extremely large ranges. Therefore, the equation is only proposed for rates of change of 20 deg.

If it is desired to make inferences on one or the other of SS or p this can be done as shown in the following example:

<u>Example</u> Suppose that the planned values of p, SS are respectively, 0.005, 0.70 and that N = 10,000 "parts". After an assembly level temperature cycling screen X = 17 dropouts are observed.

The planned mean number of drop-outs = μ_p = 10,000 (0.005) (0.70) = 35 and the lower and upper bounds from the adaptive routines are (20, 51) and since 17 does not lie between 20 and 51 (inclusive) the screen has not behaved as planned. Assuming the planned p = 0.005 is about correct = μ_p obs. drop-outs = 17 = NpSS. This means SS = 17/50 = 0.34.

This estimated screening strength is considerably different than 0.70 and an adjustment in the screening parameters is indicated. If a confidence interval on the true SS (assuming p = 0.005 is correct) is desired it can be obtained from a confidence interval for μp. Based on X=17 a 0.99 confidence interval is (see page 190, Handbook of Probability and Statistics, Chemical Rubber Co., 1966 Cleveland, Ohio 44114 for ready to use tables)

$$P(8.2 < \mu < 30.7/X=17, p=0.005)=0.99$$

Dividing each endpoint by Np = 50

$$P(0.164 < SS < 0.614/X=17, p=0.005)=0.99$$

and (0.164,0.614) is and 0.99 confidence interval for SS.

The SDO model has, in addition to the expected total dropouts (and the accompanying 0.99 bounds) the similar numbers for part/component dropouts and workmanship/manufacturing defects separately. Thus, if the user can classify failures into two categories: parts/components versus workmanship/manufacturing separate checks can be made of the expected dropouts as described in the above example.

B.1.2 <u>Adaptive Screening for Unit/System Level Screens</u>: In a unit/system level screen, failures that are precipitated will be repaired; an entire unit or system will not be discarded. Thus a model is needed to compute the expected number of failures in the selected test time T. In Ref. 22, a Chance Defective Exponential (CDE) time-to-failure distribution was introduced:

$$P\ (\text{unit lifetime} \leq t) = \left[\exp - (a_0 t + a_1 (1-e^{-a_2 t}))\right] ,t>0,\ a_0,a_1,a_2>0$$

APPENDIX B

STATISTICAL ASPECTS OF ADAPTIVE SCREENING

B.1 Adaptive Screening One of the cardinal "rules-of-thumb" of stress screening is that a screen should never be selected or applied without an idea of its screening strength (SS = probability of detecting a latent defect given that a latent defect is present).

In order to monitor and control a stress screening program, even one consisting only of a single screen, it is necessary to compare the actual results of the screen to the planned results. The results of a screen are commonly of two forms:

i) number of dropouts/failures

ii) times to failure

The first is usually called "attribute" data and the latter is called "variables" data.

B.1.1 Adaptive Screening for Dropout/Failure Data:

Suppose that prior to the running of a given screen the planned (from, say, the screening strength equations) SS has been determined; suppose also the same is true of the incoming latent defect rate p. Further, let N denote the known or estimated total number of opportunities for latent defects to occur (usually parts, connections, solder joints, etc.). The probability distribution of X, the number of drop-outs, is

$$P(X=x) = \binom{N}{x} (pSS)^x (1-pSS)^{N-x}, \text{ that is}$$

X has a binomial distribution. Since pSS is usually quite small (e.g. < 0.01) and N quite large (e.g. > 1000) the Poisson distribution is used (in the adaptive routine of the SDO model):

$$P(X=x)=(e^{-\mu} \mu^x)/x! \quad \mu=NpSS.$$

The SDO adaptive routine uses the planned values (from the main program) for p and SS to compute $NpSS \equiv \mu_p$ and using a computer routine prints out the upper and lower bounds on the total OBSERVED number of drop-outs based on a 0.99 probability interval. That is, if the observed number of drop-outs (symbolized by X above) is outside the bounds, the screening is not behaving as planned.

APPENDIX C

THE CHANCE DEFECTIVE EXPONENTIAL (CDE) MODEL

The CDE Model:

$$\bar{F}_s(t)=P(\text{unit life} > t)=\exp\left[-(a_0t+a_1\,(1-e^{-a_2t}))\right] \qquad \text{(C-1)}$$

is extremely attractive. It arises from reasonable physical considerations and it can furnish a direct (unconfounded with p) estimate of screening strength (SS).

Actually the CDE of C-1 involves two assumptions that need not be made and that do not seem to improve it's tractability. The assumption that the probability distribution of n (the random number of latent defects) is Poisson (with mean $a_1 = Np$) may be replaced by the exact binomial distribution:

$$P(n) = \binom{N}{n} p^n(1-p)^{N-n} \qquad \text{(p = the probility of a latent defect)}$$

Also it was assumed that the total failure for all of the good parts (of which there are actually N-n) is a constant a_0. If we write a_0' for the failure rate of a <u>single</u> good part and remove both of these assumptions.

$$\bar{F}_s(t) = \left[(1-p)\, e^{-a_0't} + pe^{-a_2t}\right]^N.$$

The form (C-1) of the CDE has three unknown parameters $\underline{a} = (a_0, a_1, a_2)$ while the "exact" CDE above has four parameters - or does it? The parameter N is known so that the only unknown parameters are a_0' , a_2 , p.

A quantity of interest is the probability that a defective unit (symbolized by D) will live through the test i.e. (if t= unit life), $P(t > T/D)$, it can and has been shown that:

$$P(t>T|D) = \frac{e^{-\left[a_0T + a_1\,(1-e^{-a_2T})\right]} - e^{-\left[a_1 + a_0T\right]}}{(1-e^{-a_1})} \qquad \text{(C-2)}$$

The screening strength (SS) per latent defect is

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It will be assumed, as in Ref. 22, that the unit/system failure process is a Nonhomogeneous Poisson Process (NHPP) with the mean value function (say M(t)) of the CDE:

$$M(t)=\text{Expected \# of occurrences in } (0,t)=a_0t+a_1(1-e^{-a_2t})$$

The CDE arises naturally: assuming that a group of N parts contains n<<N latent defect parts with constant failure rate a_2; a large number (N-n) of good parts with constant failure rate (for the totality of good parts) a_0; and expected number of latent defect parts $a_1=Np$ (p = the incoming latent defect rate) then the probability of survival of a system comprised a total of N parts (given n latent defective parts) is P (system live > t/n bad parts)

$$=(e^{-a_0t})\left[e^{-a_2nt}\right]$$

Multiplying by probability of n latent defective parts, namely

$$(e^{-a_1}a_1^n)/n!$$

and summing out n, the unconditional survival distribution is

$$P(\text{unit life time} > t) \equiv \bar{F}_s(t)=\exp -\left[a_0t+a_1(1-e^{-a_2t})\right]$$

Since $a_1 = Np$, $a_0 = N\lambda g$ = failure rate of a good part, $a_2 = k\lambda g$ (latent defect failure rate),

PLANNED values of $a = (a_0, a_1, a_2)$, say $\underline{a}^* = (a_0^*, a_1^*, a_2^*)$

can be obtained. The planned expected number of occurrences in a screen of length T is

$$M(T)=a_0^*T+a_1^*(1-e^{-a_2^*T})$$

and this is the value computed by the adaptive routine at the unit/system level screens.

When the actual failure times (during the unit/system level screen) are available, which is usually very costly, the parameter vector $\underline{a}$ might be estimated and more extensive data analysis performed. This topic is discussed in the Appendix C. At this point such data analysis is too costly and intractable for the adaptive routine.

maximizing vector $\hat{\underline{a}}$ are said to be the maximum likelihood estimates (MLE's). On the other hand one might differentiate (C-4) or its logarithim with respect a_0, a_1, a_2, and iteratively solve three equations in three unknowns.

There are non-trivial problems with either approach, starting points are required and these are not easy to come by. Also the orders of magnitude of a_0, a_1, a_2, are quite different which causes other problems. Usually good starting points are obtained by using another method of estimation. For example the moment estimates of $\underline{a}$ say $\bar{\underline{a}}$ $(\bar{a}_0, \bar{a}_1, \bar{a}_2)$ could be used as starting points or in the worst case they could be used as estimates directly. Unfortunately the moments of the CDE, even the first (the mean) are intractable. All this discussion leaves aside the important question: over the space of all possible observed data $\{t_{ij}\}$ for which sets of t_{ij} will the maximum of (C-4) exist and/or be unique?

However, assuming a user can obtain estimates of $\underline{a}$ which to him are satisfactory the direct estimate of SS can be obtained, namely, $1-e^{-\hat{a}_2 T}$

In fact, there is another approach to estimating $\underline{a}$. It is the non-linear squares approach using the observed cumulative failures as the dependent variable and fitting the observed cumulative failures to the mean value function,

$$M(t) = a_0 t + a_1 (1-e^{-a_2 t})$$

From a purely statistical standpoint this method is not as satisfying as the maximum likelihood method. Indeed the method considered here would better be called "pseudo" least squares. The UCLA BIOMED CAL non-linear least squares program (BMDO7R) seems to have problems of convergence and starting points as well.

$$SS = 1 - \exp(-a_2 T) \qquad \text{(C-3)}$$

Thus, if a_2 can be estimated the component screening strength can be estimated directly (i.e. without being confounded with the incoming latent defect rate p.)

In fact the only method of estimating SS directly (other than the above method) which is known is that of "seeding" latent defects so that the number initially present is known. This latter approach has serious shortcomings. For example some latent defects are impossible to seed or perhaps a better word would be impossible to "simulate".

Unfortunately, obtaining estimates of the vector $\underline{a}$ in the CDE model is difficult even though Fertig (Ref. 22) presented some successful cases.

The likelihood function (i.e. the joint probability density of the failure times) is

$$\prod_{j=1}^{N} (1 - F(T_j; \underline{a})) \prod_{i=1}^{r_j} (a_0 + a_1 a_2 e^{-a_2 t_{ij}}) \qquad \text{(C-4)}$$

where: N = number of systems under test (screen)

T_j = length of test for jth system

r_j = number of failures observed on the jth system

t_{ij} = the ith the failure time ($i=1,\ldots,r_j$) on the jth system

$t_{ij} < t_{i+1,j}$, $i = 1,\ldots, r_j-1$

$1-F(T_j;\underline{a}) = \bar{F}_s(T)$ given in (C-1)

Usually the N systems are all on the same screen and hence $T_j \equiv T$ for all j. It is also not uncommon that $N = 1$.

In any case, based on the failure times the function (in C-4)) can theoretically be evaluated by optimization techniques to find the vector $\hat{a} = (\hat{a}_0, \hat{a}_1, \hat{a}_2)$ which makes (C-4) the largest, i.e., maximizes (C-4). The components of the

APPENDIX E

LONG TERM FIELD RELIABILITY IMPROVEMENT THROUGH NATURAL LATENT DEFECT REDUCTION

If N represents the total number of opportunities (parts, solder joints, connections et. al.) for a latent defect and if p is the probability of occurrence of a latent defect, then when an assembly, unit or equipment has been constructed the probability that exactly n of the N opportunities represent latent defects is given by the binomial distribution:

$$P(n) = \binom{N}{n} p^n (1-p)^{N-n}$$

which, because N is usually large and p usually small, is well-approximated by the Poisson distribution.

However, the major point of consideration is the behavior of n (the number of latent defects) and p (the latent defect rate or probability of occurrence) as the unit is operated for a long time in the field. Indeed suppose each time the unit fails, with constant rate $(N-n)\lambda g$ for the good "parts" and constant rate $nk\lambda g$ for the bad "parts", that it is repaired with a good "part" with probability $1-p$ and repaired with a bad (latent defect) "part" with probability p. That is, it is assumed that the repairs are made at the same (latent) defect rate as that which previously existed (when the unit was built). The factor $k > 1$ is the ratio of the latent defect failure rate to the good part failure rate.

It can be shown that as t (operating time) $\to \infty$

$$P(n) = \binom{N}{n} (p^*)^n (1-p^*)^{N-n} \qquad \text{(E-1)}$$

where $$p^* = \frac{p}{k(1-p) + p} \approx \frac{p}{k}$$

This does <u>not</u> mean that the random number of latent defects, n, will approach a constant and stay there; it means that n will vary, with mean Np^*. It also means that the long-run latent defect probability is p^*.

Note also that since $k > 1$, $p^* < p$ always.

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APPENDIX D

APPROXIMATION OF SCREENING STRENGTH USING OBSERVED MTBF

Here it is assumed that, at the equipment or system level, estimates of the MTBF with and without a particular "screening sequence" (perhaps consisting of only one screen) are available.

Let N be the number of opportunities (parts connections) for the occurrence of a latent defect in an equipment or system. Then, in terms of expected values, the system failure rate at time t = 0 and prior to a screen is

$$\lambda_{u.s.} = N\,(1-p)\lambda_g + Npk\lambda_g \qquad \text{(D-1)}$$

where: k > 1 is the factor which when multiplied by the non-defective part failure rate yields the latent defect part failure rate; p is the latent defect occurrence probability (rate) and u.s. represents unscreened.

After the screen, in terms of expected values the equipment/system failure rate is

$$\lambda_s = N\left[(1-p)(1-SS)\right]\lambda_g + Npk\lambda_g\,(1-SS) \qquad \text{(D-2)}$$

where: SS is the screening strength of the screen. Using (D-1) and (D-2)

$$SS = (\lambda_{u.s.}-\lambda_s)/(\lambda_{u.s.}-N\lambda) \qquad \lambda_s > N\lambda$$

The largest SS can be is when $N\lambda=\lambda_s$; then SS is one. The smallest SS can be is when $N\lambda \to 0$ and then it is $1 - (\lambda_s/\lambda_{u.s.})$

$$= 1 - \frac{MTBF_{u.s.}}{MTBF_s}\ .$$

Example: Suppose that two pieces of electrical equipment have MTBF's (field observed) of 100 and 250, respectively, and that the first (100 hr. MTBF) has been unscreened while the latter (250 hr. MTBF) was subjected to a 15 min. 6g (RMS) random vibration screen. Then the strength of that screen, namely SS, is at least 1-100/250 = 0.6.

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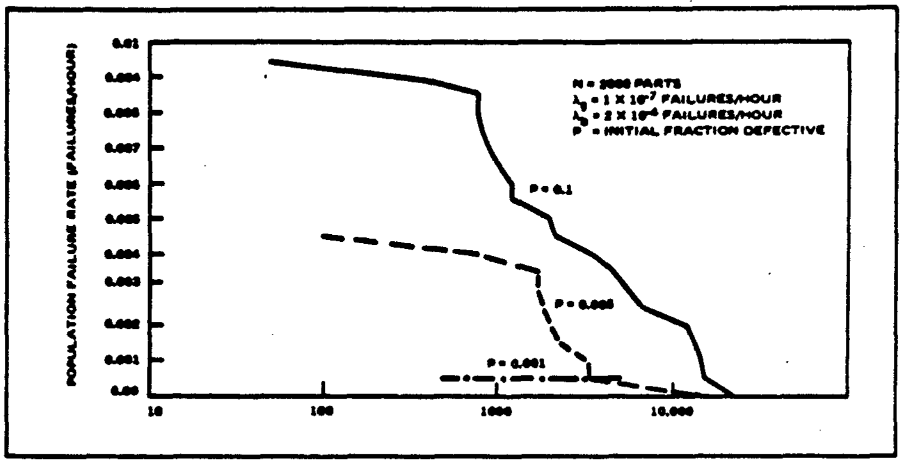

Figure E.1. Decreasing Failure Rate with Time, 2,000 Parts

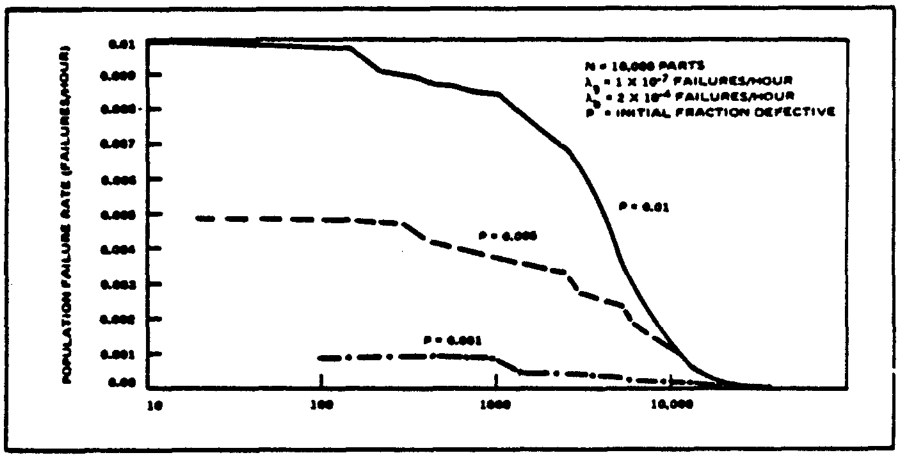

Figure E.2. Decreasing Failure Rate with Time, 10,000 Parts

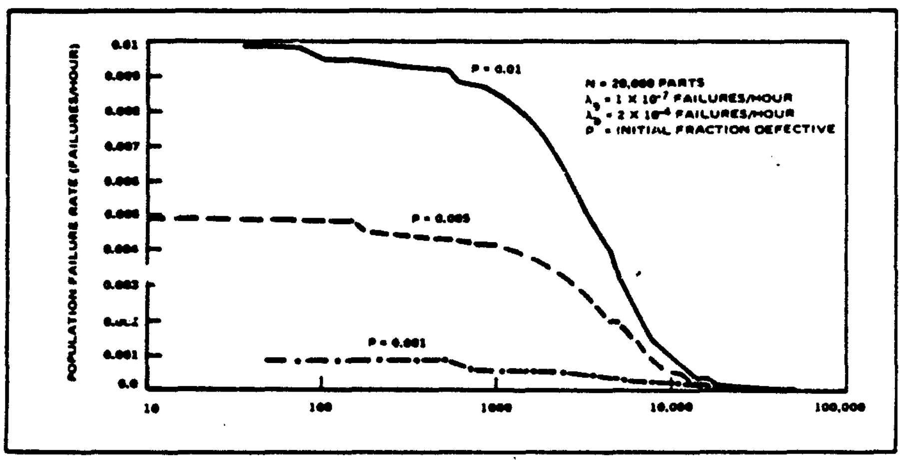

Figure E.3. Decreasing Failure Rate with Time, 20,000 Parts

Example: Suppose $N = 2000$, $p = 0.005$, $\lambda g = 10^{-7}$ and $k = 2x10^{3}$.

Then

$$p^* = \frac{0.005}{1990 + .005} = 2.5 \times 10^{-6}$$

An important question is: how long does it take to approach (E-1). The mathematical result requires $t \to \infty$. The accompanying three figures give an idea of the rate of decrease for nine typical cases: p = .001, .005 and .01,

$p = 0.001, 0.005$, and 0.01

$N = 2000, 10{,}000$, and $20{,}000$

$$\lambda_g = 10^{-7}$$

$$k\lambda g = 2 \times 10^{-4}$$

The data in the three figures were derived from a simulation program which simulated failures of both good and bad parts and replacement of the failed part from populations containing p fraction defective.

TABLE F.1 SSM Internal Constants.

Description	Internal Value	Lines in Program Where Appears
If two (MTBF, cost) pairs differ by less than this amount during the optimization one of them is eliminated from consideration	0.00001	Program PREFIX.SDO.FORT, line: MAIN 200
Number of divisions in the range of the parameter to be optimized upon.	5	Program PREFIX.SDO.FORT, line: MAIN 190 (Note: Arrays will need to be made extremely large if this is increased).
Multipliers which yield failure rates of latent defective parts and workmanship (multiplied times failure rate of good parts or workmanship).	(parts) 2×10^3 (wkm) 1×10^3	Program PREFIX.SDO.FORT, lines: MAIN 2220 MAIN 2230
Repair costs: Assembly Unit System	 $45 $300 $990	Program SDO.FORT, lines: DATA 890 DATA 910 DATA 930
Percent of test time considered labor time. Assembly Unit System	 15% 15% 100%	Program SDO1.FORT, lines: SSPR200 through SSPR1100 (each test can be handled separately).

APPENDIX F

MODEL COMPUTER PROGRAM LISTINGS

The three computer programs comprising the SSM are,

1) PREFIX

2) SD01

3) ADAPT

Listings of those programs are contained in this appendix. Below is a table of internal constants, identifying the values assigned to the constants and the line number in the program where that constant can be found. This enables the user to modify the program by altering the constants to more closely fit the users own hardware characteristics, production processes and screening conditions.

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PROGRAM LISTING FOR PREFIX. SDO. FORT

TABLE F.1 SSM Internal Constants (Continued)

Description	Internal Value	Lines in Program Where Appears
Detection Probability (probability of detection is inherent in screening strength equations)	1	Program SD01.FORT, line: DATA 390
Maximum duration of suggested improved screen in "Adapt"		Program ADAPT.FORT, lines:
Constant Temperature	240 hours	SOLV220
Cycled Temp.	40 cycles	SOLV250
Vibration	60 min.	SOLV280
No. of levels	3	Program PREFIX.SDO.FORT, lines: MAIN 210
Number of Rework Cycles	1	(Requires fairly extensive rewriting)
Starting points for ZXSSQ	Computed from model data is expected values for a_1, a_2	Program ADAPT.FORT, lines: OPT180-190
Convergence Criterion and Options for ZXSSQ	See documentation for ZXSSQ.	Program ADAPT.FORT, lines: OPT100-170

```
      READ (5,*) BMIN11(KZ),BMAX12(KZ)
      BMIN12(KZ)=0.
      IF (OPTC.EQ.1.0) BMIN12(KZ)=BMAX12(KZ)
      BMAX11(KZ)=BMIN11(KZ)
      GO TO 180
60    IF (ISCR(KZ).NE.2) GO TO 80
      WRITE (6,410) KZ
      IF (OPTC.EQ.1.) GO TO 70
      WRITE (6,420)
      READ (5,*) IDCYT
      IF (IDCYT.NE.0) GO TO 70
      BMAX21(KZ)=71.0
      BMIN21(KZ)=71.0
      BMAX22(KZ)=-54.0
      BMIN22(KZ)=-54.0
      BMAX23(KZ)=5.0
      BMIN23(KZ)=5.0
      BMAX24(KZ)=20.0
      BMIN24(KZ)=0.0
      IF (OPTC.EQ.1.0) BMIN24(KZ)=BMAX24(KZ)
      GO TO 180
70    WRITE (6,430)
      READ (5,*) BMAX21(KZ),BMAX22(KZ),BMAX23(KZ),BMAX24(KZ)
      BMIN24(KZ)=0.
      IF (OPTC.EQ.1.0) BMIN24(KZ)=BMAX24(KZ)
      BMIN21(KZ)=BMAX21(KZ)
      BMIN22(KZ)=BMAX22(KZ)
      BMIN23(KZ)=BMAX23(KZ)
      GO TO 180
80    IF (ISCR(KZ).NE.3) GO TO 120
      WRITE (6,440) KZ
      IF (OPTC.EQ.1.0) GO TO 90
      WRITE (6,450)
      READ (5,*) IDRV
      IF (IDRV.NE.0) GO TO 90
      BMAX31(KZ)=6.0
      BMIN31(KZ)=6.0
      BMAX32(KZ)=10.0
      BMIN32(KZ)=0.0
      IF (OPTC.EQ.1.0) BMIN32(KZ)=BMAX32(KZ)
      GO TO 180
90    WRITE (6,460)
      READ (5,*) BMAX31(KZ),BMAX32(KZ)
      IF (BMAX31(KZ).LE.7.5) GO TO 100
      BMAX31(KZ)=7.5
      WRITE (6,470)
      GO TO 110
100   IF (BMAX31(KZ).GE.0.6) GO TO 110
      BMAX31(KZ)=0.6
      WRITE (6,480)
110   BMIN32(KZ)=0.0
      BMIN31(KZ)=BMAX31(KZ)
      IF (OPTC.EQ.1.0) BMIN32(KZ)=BMAX32(KZ)
      GO TO 180
120   IF (ISCR(KZ).NE.4) GO TO 150
```

```
      WRITE (6,490) KZ                                        MAIN1110
      IF (OPTC.EQ.1.) GO TO 130                               MAIN1120
      WRITE (6,500)                                           MAIN1130
      READ (5,*) IDSSV                                        MAIN1140
      IF (IDSSV.NE.0) GO TO 130                               MAIN1150
      BMAX41(KZ)=6.0                                          MAIN1160
      BMIN41(KZ)=6.0                                          MAIN1170
      BMAX42(KZ)=10.0                                         MAIN1180
      BMIN42(KZ)=0.0                                          MAIN1190
      IF (OPTC.EQ.1.0) BMIN42(KZ)=BMAX42(KZ)                  MAIN1200
      GO TO 180                                               MAIN1210
130   WRITE (6,510)                                           MAIN1220
      READ (5,*) BMAX41(KZ),BMAX42(KZ)                        MAIN1230
      IF (BMAX41(KZ).LE.14.0) GO TO 140                       MAIN1240
      BMAX41(KZ)=14.0                                         MAIN1250
      WRITE (6,520)                                           MAIN1260
140   BMIN42(KZ)=0.0                                          MAIN1270
      IF (OPTC.EQ.1.0) BMIN42(KZ)=BMAX42(KZ)                  MAIN1280
      BMIN41(KZ)=BMAX41(KZ)                                   MAIN1290
      GO TO 180                                               MAIN1300
150   IF (ISCR(KZ).NE.5) GO TO 190                            MAIN1310
      WRITE (6,530) KZ                                        MAIN1320
      IF (OPTC.EQ.1.) GO TO 160                               MAIN1330
      WRITE (6,540)                                           MAIN1340
      READ (5,*) IDSFV                                        MAIN1350
      IF (IDSFV.NE.0) GO TO 160                               MAIN1360
      BMAX51(KZ)=6.0                                          MAIN1370
      BMIN51(KZ)=6.0                                          MAIN1380
      BMAX52(KZ)=10.0                                         MAIN1390
      BMIN52(KZ)=0.0                                          MAIN1400
      IF (OPTC.EQ.1.0) BMIN52(KZ)=BMAX52(KZ)                  MAIN1410
      GO TO 180                                               MAIN1420
160   WRITE (6,550)                                           MAIN1430
      READ (5,*) BMAX51(KZ),BMAX52(KZ)                        MAIN1440
      IF (BMAX51(KZ).LE.15.5) GO TO 170                       MAIN1450
      BMAX51(KZ)=15.5                                         MAIN1460
      WRITE (6,560)                                           MAIN1470
170   BMIN52(KZ)=0.0                                          MAIN1480
      IF (OPTC.EQ.1.0) BMIN52(KZ)=BMAX52(KZ)                  MAIN1490
      BMIN51(KZ)=BMAX51(KZ)                                   MAIN1500
180   WRITE (6,570) KZ                                        MAIN1510
      READ (5,*) A1A(KZ)                                      MAIN1520
      WRITE (6,580)                                           MAIN1530
      READ (5,*) B1A(KZ)                                      MAIN1540
      IF (B1A(KZ).EQ.0.0) B1A(KZ)=CPHR                        MAIN1550
      B2(KZ)=0.                                               MAIN1560
      WRITE (6,590)                                           MAIN1570
      READ (5,*) B3(KZ)                                       MAIN1580
      WRITE (6,600)                                           MAIN1590
      READ (5,*) ADEF(KZ)                                     MAIN1600
      IF (ADEF(1).EQ.0.0) ADEF(1)=.002                        MAIN1610
      IF (ADEF(2).EQ.0.0) ADEF(2)=.001                        MAIN1620
      IF (ADEF(3).EQ.0.0) ADEF(3)=.0005                       MAIN1630
190   CONTINUE                                                MAIN1640
      DO 200 IIS=1,3                                          MAIN1650
```

```
200   IF (ISCR(IIS).LE.0) ISCR(IIS)=1
      WRITE (2,*) ISCR
      WRITE (8,*) F
      DO 220 INDEX=1,M
      DO 220 INDEX2=1,5
      DUMB1=1000.
      DUMB2=1000.
      IF (ISCR(INDEX).EQ.INDEX2) GO TO 210
      WRITE (10,*) DUMB1,DUMB2
      GO TO 220
210   WRITE (10,*) A1A(INDEX),B1A(INDEX)
220   CONTINUE
      WRITE (11,610) P
      WRITE (9,620) R1,R2
      DO 230 I=1,3
      WRITE (12,*) BMAX11(I),BMIN11(I)
      WRITE (12,*) BMAX12(I),BMIN12(I)
      WRITE (12,*) BMAX21(I),BMIN21(I)
      WRITE (12,*) BMAX22(I),BMIN22(I)
      WRITE (12,*) BMAX23(I),BMIN23(I)
      WRITE (12,*) BMAX24(I),BMIN24(I)
      WRITE (12,*) BMAX31(I),BMIN31(I)
      WRITE (12,*) BMAX32(I),BMIN32(I)
      WRITE (12,*) BMAX41(I),BMIN41(I)
      WRITE (12,*) BMAX42(I),BMIN42(I)
      WRITE (12,*) BMAX51(I),BMIN51(I)
      WRITE (12,*) BMAX52(I),BMIN52(I)
230   CONTINUE
      WRITE (4,*) NCYC,M,NPARTS,CREQD,E,ITV,XMTBF,CPHR
      WRITE (4,630)
      WRITE (4,*) POEF
      DO 240 IX=1,M
240   WRITE (4,*) ADEF(IX)
      WRITE (4,630)
      DO 260 IX=1,M
      DO 250 IU=1,5
250   WRITE (4,*) B2(IX),B3(IX)
260   CONTINUE
      GO TO 300
270   WRITE (6,640)
      WRITE (6,650)
      READ (5,*) XMTBF
      IF (XMTBF.EQ.0.) GO TO 280
      CREQD=0.
      GO TO 290
280   WRITE (6,660)
      READ (5,*) CREQD
      IF (CREQD.NE.0.0) GO TO 290
      CREQD=1.E10
      OPTC=1.0
290   WRITE (6,670)
      READ (5,*) NPARTS
      WRITE (6,680)
      READ (5,*) XLAMP1,XLAMC1
      IF (XLAMP1.EQ.0.0) XLAMP1=1.E-7
```

```
      IF (XLAMC1.EQ.0.0) XLAMC1=1.E-10
      XLAMP2=2.E3*XLAMP1
      XLAMC2=1.E3*XLAMC1
      NOP=21.6*NPARTS
      WRITE (13,*) NOP,XLAMP1,XLAMP2,XLAMC1,XLAMC2
      WRITE (6,690)
      READ (5,*) PDEF
C     WRITE(6,586)
C     READ(5,*)CPHR
      CPHR=30.
      GO TO 10
300   STOP
C
310   FORMAT (1X////14X,8('*'),'TEST AND PARAMETER SELECTION',8('*')///)
320   FORMAT (1X//5X,'FOLLOWING ',' ARE THE AVAILABLE SCREENS :'//5X,'1.
     1 CONSTANT',' TEMPERATURE'/5X,'2.  CYCLED TEMPERATURE'/5X,'3.  RAN
     2DOM VIBRATION'/5X,'4.  SINE SWEEP',' VIBRATION'/5X,'5.  SINE FIXED
     3 VIBRATION'//)
330   FORMAT (5X/5X,'DEFAULTS ARE:'/10X,'LEVEL 1',10X,'LEVEL 2',10X,'LEV
     1EL 3'/6X,'TEMP. CYCLING',7X,'RAN.VIB',7X,'CONST. TEMP.'/11X,'(2)',
     214X,'(3)',14X,'(1)'////)
340   FORMAT (5X,'IF YOU WISH DEFAULT SCREENS ENTER ZERO, IF NOT,',' ENT
     1ER 1:')
350   FORMAT (1X//5X,'ENTER YOUR SCREEN SEQUENCE AS PROMPTED USING ','NUM
     1BERS FROM ABOVE LISTING:'/5X,'IF YOU DO NOT WISH TO SCREEN ','AT
     2A PARTICULAR LEVEL, ENTER ZERO:')
360   FORMAT (1X,'FOR LEVEL',I2,' THE SCREEN NUMBER DESIRED IS:')
370   FORMAT (1X///24X,8('*'),'LEVEL',I2,8('*')////)
380   FORMAT (5X,'CONSTANT TEMPERATURE, LEVEL',I2)
390   FORMAT (5X,'THE DEFAULT VALUES ARE:'/5X,'TEMPERATURE=70 DEG C'/5X,
     1'TIME RANGE TO BE INVESTIGATED=0 TO 48 HOURS'/5X,'IF YOU WISH THE
     2DEFAULT VALUES, ENTER ZERO, IF NOT,','ENTER 1:')
400   FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'T
     1EMP IN DEG C. ','TIME IN HRS:'/5X,'(TEMP MUST BE LESS THAN +75 DEG
     2 C)')
410   FORMAT (5X,'TEMPERATURE CYCLING, LEVEL',I2)
420   FORMAT (5X,'THE DEFAULT ','VALUES ARE:'/5X,'LOWER TEMP=-54 DEG C'/
     15X,'UPPER TEMP=71 DEG C'/5X,'TEMP. RATE OF CHANGE=5 DEG C/MIN'/5X,
     2'RANGE OF CYCLES TO BE',' INVESTIGATED=0 TO 20'/5X,'IF YOU WISH TH
     3E DEFAULT VALUES ','ENTER ZERO, IF NOT, ENTER 1:')
430   FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'U
     1PPER TEMP.,LOWER TEMP.,TEMP. RATE OF CHANGE, NO.',' OF CYCLES:'/5X
     2,'(TEMPERATURE RANGE MUST BE WITHIN -55 TO +75',' DEG C'/5X,'AND R
     3ATE OF CHANGE BETWEEN 1 AND 20 DEG C/MIN)')
440   FORMAT (5X,'RANDOM VIBRATION, LEVEL',I2)
450   FORMAT (5X,'THE DEFAULT VALUES',' ARE:'/5X,'G-LEVEL=6 G'/5X,'RANGE
     1 OF TIME TO BE INVESTIGATED=0 TO 10 MIN.'/5X,'IF YOU WISH THE DEFA
     2ULT VALUES ENTER ZERO, IF NOT, ENTER 1:')
460   FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'G
     1 LEVEL,',' TIME IN MIN:'/5X,'(G LEVEL MUST BE BETWEEN .6 AND 7.5)'
     2)
470   FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--PARAMETER SET AT 7.5',
     1' G.')
480   FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--PARAMETER ','SET AT 0.
     16 G.')
```

```
490   FORMAT (5X,'SINE SWEEP VIBRATION, LEVEL',I2)                      MAIN2760
500   FORMAT (5X,'THE DEFAULT VALUES ARE:'/5X,'G-LEVEL=6 G'/5X,'RANGE ',MAIN2770
     1'OF TIME TO BE INVESTIGATED=0 TO 10 MIN.'/5X,'IF YOU',' WISH THE DMAIN2780
     2EFAULT VALUES, ENTER ZERO, IF NOT, ENTER 1:')                     MAIN2790
510   FORMAT (5X,'ENTER IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'G-MAIN2800
     1LEVEL, TIME IN MIN:'/5X,'(G LEVEL BETWEEN 0 AND 10)')             MAIN2810
520   FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--','PARAMETER SET AT 14MAIN2820
     1.0 G')                                                            MAIN2830
530   FORMAT (5X,'SINE-FIXED FREQ. VIBRATION, LEVEL',I2)                MAIN2840
540   FORMAT (5X,'THE DEFAULT VALUES ARE:'/5X,'G-LEVEL=6 G'/5X,'RANGE OFMAIN2850
     1',' TIME TO BE INVESTIGATED=0 TO 10 MIN'/5X,'IF YOU WISH THE ','DEMAIN2860
     2FAULT VALUES ENTER ZERO, IF NOT, ENTER 1:')                       MAIN287u
550   FORMAT (5X,'ENTER, IN ORDER, SEPARATED BY COMMAS OR SPACES:'/5X,'GMAIN2880
     1-LEVEL, TIME IN MIN:'/5X,'(G-LEVEL BETWEEN 1 AND 10)')            MAIN2890
560   FORMAT (5X,'G-LEVEL OUT OF ALLOWABLE RANGE--','PARAMETER SET AT 15MAIN2900
     1.5 G')                                                            MAIN2910
570   FORMAT (1X/5X,'ENTER THE FOLLOWING MANUFACTURING PROCESS DATA',', MAIN2920
     1LEVEL',I2//5X,'IF MODEL DEFAULTS ARE DESIRED FOR ANY ITEM, ENTER ZMAIN2930
     2ERO:'//5X,'FIXED TEST COST IN DOLLARS=')                          MAIN2940
580   FORMAT (5X,'VARIABLE TEST COST IN DOLLARS PER HOUR=')             MAIN2950
590   FORMAT (5X,'AVERAGE COST IN DOLLARS FOR REPAIR OF DEFECT',' DETECTMAIN2960
     1ED AT THIS LEVEL=')                                               MAIN2970
600   FORMAT (5X,'ASSEMBLY DEFECTS AT THIS LEVEL AS A FRACTION ','OF TOTMAIN2980
     1AL PARTS=')                                                       MAIN2990
610   FORMAT (1X,F4.1)                                                  MAIN3000
620   FORMAT (2(1X,F10.6))                                              MAIN3010
630   FORMAT (1X)                                                       MAIN3020
640   FORMAT (5X///14X,8('*'),' SELECTION OF PROGRAM INPUTS AND ','OPTIMAIN3030
     1ONS ',8('*')//5X,'IF THE MODEL DEFAULT IS DESIRED, ENTER ZERO:'//5MAIN3040
     2X,'OPTION A FINDS OPTIMAL TEST SEQUENCE TO ACHEIVE A',' GIVEN PROOMAIN3050
     3UCT'/5X,' RELIABILITY REQUIREMENT'//5X,'OPTION B ','OPTIMIZES PRODMAIN3060
     4UCT RELIABILITY GIVEN A FIXED COST'//5X,'OPTION C COMPUTES TEST STMAIN3070
     5RENGTHS OF EXISTING SCREENS'//)                                   MAIN3080
650   FORMAT (1X/5X,'DESIRED SERIES MTBF OF NEW SYSTEM (OPTION A ','ONLYMAIN3090
     1,FOR OPTIONS B OR C '/5X,'ENTER ZERO)')                           MAIN3100
660   FORMAT (1X/5X,'COST BUDGET(OPTION B ONLY,','FOR OPTION A OR C ENTEMAIN3110
     1R ZERO)')                                                         MAIN3120
670   FORMAT (1X/5X,'TOTAL PART POPULATION(NO DEFAULT AVAILABLE)')      MAIN3130
680   FORMAT (1X/5X,'FAILURE RATES OF GOOD PARTS; GOOD CONNECTIONS=')   MAIN3140
690   FORMAT (1X,5X,'PART QUALITY DEFECTS AS A FRACTION OF TOTAL',' PARTMAIN3150
     1S=')                                                              MAIN3160
      END                                                               MAIN3170
```

PROGRAM LISTING FOR SDO1. FORT

```
      INTEGER T
      INTEGER*2 TV(20,300),SEQ(20,300),TV1(17000),SEQ1(17000)
      DIMENSION N(5), ADEF(5), F(11,4,5), R1(11,4,5), R2(11,4,5),
     +CT(5,5),
     1CR1(5,5), CR2(5,5), TS(20,1500), TC(20,1500), N1(20), NF(20), ISCR
     2(3), P(11,4,5), TS1(17000), TC1(17000), SCOST(5,5), IARRAY(20),
     +TIME(3,5),
     3 TSS(20,1500), PARRAY(11,4,5), AMAX11(3), AMIN11(3), AMAX12(3),
     4 AMIN12(3), AMAX21(3), AMIN21(3), AMAX22(3), AMIN22(3), AMAX23(
     53), AMIN23(3), AMAX24(3), AMIN24(3), AMAX31(3), AMIN31(3), AMAX32(
     63), AMIN32(3), AMAX41(3), AMIN41(3), AMAX42(3), AMIN42(3), AMAX51(
     73), AMIN51(3), AMAX52(3), AMIN52(3), X(11,4,5),TSS1(17000)
      DATA NF,TS,TC,TSS,TSS1,TS1,TC1/20*0,141000*0./
      DATA PARRAY/220*1.0/
      DATA P,F,R1,R2/880*1.0/
      DATA N/5*5/
      COMMON ISCR
      CALL DATA (NCYC,M,PDEF,CREGO,E,ITV,N,ADEF,CPHR,P,F,R1,R2,CR1,CR2,X
     1MTBF,LEVEL,ITYP,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,A
     2MIN22,AMAX23,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAX
     341,AMIN41,AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52,NPARTS)
      READ (2,*) ISCR
      WRITE (2,*) M,NPARTS,PDEF,ADEF
      READ (13,*) XNOP,XLAMP1,XLAMP2,XLAMC1,XLAMC2
      LL=0
      ADIN=0.0
      DO 10 I=1,M
   10 ADIN=ADIN+ADEF(I)
      DIN=ADIN+PDEF
      IF (XMTBF.EQ.0.0) GO TO 20
      FRF=1./XMTBF
      FRM=0.0
      OPTS=0.0
      OPTS2=0.0
      HOURS2=0.0
      SREGO=XMTBF
   20 DO 180 I1=1,M
      NI1=N(I1)
      DO 170 I2=1,NI1
      LL=LL+1
      MV=0
      READ (10,*,END=30) A1,B1
      GO TO 40
   30 A1=0.0
      B1=0.0
   40 DO 90 KK4=1,ITV
      DO 90 KK3=1,ITV
      DO 70 KK2=1,ITV
      DO 60 KK1=1,ITV
      MV=MV+1
      DO 50 I=1,NCYC
   50 PARRAY(I,I1,I2)=P(I,I1,I2)
      CALL SSPROB (KK1,KK2,KK3,KK4,I1,I2,PARRAY,NCYC,CT,A1,B1,ITV,HOURS,
     1CPHR,TIME,AMAX11(I1),AMIN11(I1),AMAX12(I1),AMIN12(I1),AMAX21(I1),A
     2MIN21(I1),AMAX22(I1),AMIN22(I1),AMAX23(I1),AMIN23(I1),AMAX24(I1),A
```

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     3MIN24(I1),AMAX31(I1),AMIN31(I1),AMAX32(I1),AMIN32(I1),AMAX41(I1),AMAIN 540
     4MIN41(I1),AMAX42(I1),AMIN42(I1),AMAX51(I1),AMIN51(I1),AMAX52(I1),AMAIN 550
     5MIN52(I1))                                                        MAIN 560
      CALL SCREEN (NCYC,M,N,POEF,DIN,ADEF,PARRAY,F,R1,R2,CT,CR1,CR2,SS,SMAIN 570
     1M,TCOST,I1,I2,SCOST,TCMIN,0.0,TIME,NPARTS,XNOP,XLAMP1,XLAMP2,XLAMCMAIN 580
     21,XLAMC2,X)                                                       MAIN 590
      TSS(LL,MV)=SS                                                     MAIN 600
      TS(LL,MV)=SM                                                      MAIN 610
      TC(LL,MV)=TCOST                                                   MAIN 620
60    CONTINUE                                                          MAIN 630
70    CONTINUE                                                          MAIN 640
      IF ((I2-1)*(I2-3)*(I2-4)*(I2-5)) 80,100,80                        MAIN 650
80    CONTINUE                                                          MAIN 660
90    CONTINUE                                                          MAIN 670
100   CONTINUE                                                          MAIN 680
      DO 110 I=1,NCYC                                                   MAIN 690
110   PARRAY(I,I1,I2)=1.0                                               MAIN 700
      N1(LL)=MV                                                         MAIN 710
      IF (LL-2) 170,120,130                                             MAIN 720
120   K1=N1(LL-1)                                                       MAIN 730
      GO TO 140                                                         MAIN 740
130   K1=K                                                              MAIN 750
140   K2=N1(LL)                                                         MAIN 760
      NSEQ=K1*K2                                                        MAIN 770
      DO 150 J1=1,K1                                                    MAIN 780
      DO 150 J2=1,K2                                                    MAIN 790
      W=TSS(LL,J2)*(1.0-TSS(LL-1,J1))+TSS(LL-1,J1)                      MAIN 795
      U=TS(LL-1,J1)+(1.-TSS(LL-1,J1))*TSS(LL,J2)*TS(LL,J2)              MAIN 800
      V=TC(LL-1,J1)+(1.-TSS(LL-1,J1))*TSS(LL,J2)*TC(LL,J2)              MAIN 810
      NF(LL)=NF(LL)+1                                                   MAIN 820
      JJ=NF(LL)                                                         MAIN 830
      SEQ1(JJ)=J1                                                       MAIN 840
      TV1(JJ)=J2                                                        MAIN 850
      TS1(JJ)=U                                                         MAIN 860
      TC1(JJ)=V                                                         MAIN 870
      TSS1(JJ)=W                                                        MAIN 865
150   CONTINUE                                                          MAIN 880
      CALL RANK (TS1,TC1,TSS1,NSEQ,SEQ1,TV1)                            MAIN 890
      QC=0.0                                                            MAIN 900
      QS=0.0                                                            MAIN 910
      K=0                                                               MAIN 920
      DO 160 I=1,NSEQ                                                   MAIN 930
      IF ((TS1(I).EQ.0.0).OR.(TC1(I).EQ.0.0)) GO TO 160                 MAIN 940
      IF ((TS1(I)-QS)/TS1(I).LT.E) GO TO 160                            MAIN 950
      IF ((TC1(I)-QC)/TC1(I).LT.E) GO TO 160                            MAIN 960
      QC=TC1(I)                                                         MAIN 970
      QS=TS1(I)                                                         MAIN 980
      K=K+1                                                             MAIN 990
      TC(LL,K)=TC1(I)                                                   MAIN1000
      TS(LL,K)=TS1(I)                                                   MAIN1010
      TSS(LL,K)=TSS1(I)                                                 MAIN1015
      SEQ(LL,K)=SEQ1(I)                                                 MAIN1020
      TV(LL,K)=TV1(I)                                                   MAIN1030
      TC1(I)=0.                                                         MAIN1040
      TS1(I)=0.                                                         MAIN1050
```

```
      TSS1(I)=0.
      SEQ1(I)=0
      TV1(I)=0
160   CONTINUE
170   CONTINUE
180   CONTINUE
      CALL SEARCH (LL,K,CREQO,SREQO,SEQ,TV,TC,TSS,TS,IARRAY,TCMIN,TSMAX,
     1DIN,X)
      CALL REPORT (M,NCYC,N,ISCR,PDEF,DIN,ADEF,CPMR,P,F,R1,R2,CT,CR1,CR2
     1,IARRAY,A1,B1,ITV,TCMIN,TSMAX,NPARTS,XNOP,XLAMP1,XLAMP2,XLAMC1,XLA
     2MC2,X,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,AMIN22,AMAX
     323,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAX41,AMIN41,
     4AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52)
      DEBUG SUBCHK
      END
      SUBROUTINE SCREEN (NCYC,M,N,PDEF,DIN,ADEF,P,F,R1,R2,CT,CR1,CR2,SS,
     1SM,TCOST,I1,I2,SCOST,TCMIN,FLAG,TIME,NPARTS,XNOP,XLAMP1,XLAMP2,XLA
     2MC1,XLAMC2,X)
      DIMENSION X(11,4,5), P(11,4,5), F(11,4,5), R1(11,4,5), Q(20),
     1ISCR(3), TIME(3,5), TCOSTL(5,5), COSTL(5), N(5), CT(5,5), CR1(5,5)
     2, ADEF(5), CR2(5,5), SCOST(5,5),R2(11,4,5)
      COMMON ISCR
      PLEFT=PDEF
      IF (FLAG.GT.0.) WRITE (13,*) TIME(1,ISCR(1)),TIME(2,ISCR(2)),TIME(
     13,ISCR(3))
      IF (FLAG.GT.0.) WRITE (2,*) P(1,1,ISCR(1)),P(1,2,ISCR(2)),P(1,3,IS
     1CR(3))
      NCYC1=NCYC+1
      DO 10 I=1,NCYC1
      DO 10 J=1,M
      NJ=N(J)
      DO 10 K=1,NJ
10    X(I,J,K)=0.0
      X(1,1,1)=ADEF(1)+PDEF
      DO 50 J=1,M
      NJ=N(J)
      DO 50 K=1,NJ
      IF (K-1) 20,20,40
20    IF (J-1) 50,50,30
30    CALL MEAN (XNOP,XLAMC1,X(1,J-1,N(J-1)),TIME(J-1,N(J-1)),P(1,J-1,N(
     1J-1)),FALL)
      PLEFT=PLEFT*P(1,J-1,N(J-1))
      X(1,J,K)=X(1,J-1,N(J-1))-FALL+ADEF(J)
      GO TO 50
99    X(1,J,K)=P(1,J,K-1)*X(1,J,K-1)
      PLEFT=PLEFT*P(1,J,K-1)
      GO TO 50
40    CALL MEAN (XNOP,XLAMC1,X(1,J,K-1),TIME(J,K-1),P(1,J,K-1),FALL)
      PLEFT=PLEFT*P(1,J,K-1)
      X(1,J,K)=X(1,J,K-1)-FALL
50    CONTINUE
      IF (FLAG.GT.0.) WRITE (2,*) X(1,1,1),X(1,2,1),X(1,3,1)
C     IF (FLAG.GT.0.) WRITE(6,4000)((X(1,J,K),J=1,M),K=1,5)
      IF (FLAG.GT.0.) WRITE (2,*) X(1,1,5),X(1,2,5),X(1,3,5),PLEFT
      CLEFT=X(1,3,5)-PLEFT
```

```
      SUMX=0.
      DO 100 I=1,NCYC
      X(I+1,1,1)=0.0
      DO 60 J=1,M
      NJ=N(J.
      DO 6C K=1,NJ
60    X(I+1,1,1)=X(I+1,1,1)+(1-P(I,J,K))*F(I,J,K)*(1-R1(I,J,K))*X(I,J,K)
      DO 90 J=1,M
      NJ=N(J)
      DO 90 K=1,NJ
      IF (X(I,J,K).LT.1.0) GO TO 90
      IF (J.EQ.1.AND.K.EQ.1) GO TO 90
      IF (J.GT.1.AND.K.EQ.1) GO TO 70
      IF (J.GE.1.AND.K.GT.1) GO TO 80
      GO TO 90
70    X(I+1,J,1)=P(I+1,J-1,N(J-1))*X(I+1,J-1,N(J-1))+(1-P(I,J,1))*(1-F(I
     1,J,1))*(1-R2(I,J,1))*X(I,J,1)
      GO TO 90
80    X(I+1,J,K)=P(I+1,J,K-1)*X(I+1,J,K-1)+(1-P(I,J,K))*(1-F(I,J,K))*(1-
     1R2(I,J,K))*X(I,J,K)
90    CONTINUE
100   CONTINUE
C     IF (FLAG.GT.0.) WRITE(6,4001)((X(2,J,K),J=1,M),K=1,5)
      SUM=0.0
      DO 110 I=1,NCYC
      NM=N(M)
      SUM=SUM+X(I,M,NM)
110   CONTINUE
      DOUT=SUM
      SM=1./((XNOP-CLEFT)*XLAMC1+(FLOAT(NPARTS)-PLEFT)*XLAMP1+CLEFT*XLAM
     1C2+PLEFT*XLAMP2)
      SS=1.0-DOUT/DIN
      DELTA=DIN-DOUT
      ACOST=0.0
      TCOST=0.0
      DO 120 J=1,M
      DO 120 K=1,5
120   SCOST(J,K)=0.0
       IF(FLAG.NE.0.0) GO TO 140
      DO 130 I=1,NCYC
      CR=CR1(I1,I2)*F(I,I1,I2)+CR2(I1,I2)*(1.0-F(I,I1,I2))
      COST=CT(I1,I2)+CR*(X(I,I1,1)-X(I,I1,5))
130   ACOST=ACOST+COST
      GO TO 170
140   DO 160 J=1,M
      DO 160 K=1,5
      SUMTS1=0.0
      SUMTS2=0.0
      DO 150 I=1,NCYC
      SUMTS1=SUMTS1+(1.-P(I,J,K))*X(I,J,K)
      SUMTS2=SUMTS2+X(I,J,K)
150   CONTINUE
      IF (ISCR(J).NE.K) GO TO 160
      IF (P(1,J,ISCR(J)).GT.0.999) GO TO 160
      SCOST(J,K)=SUMTS1*CR2(J,K)+CT(J,K)
```

```
160   TCOST=TCOST+SCOST(J,K)
      SUMTC=TCOST
      GO TO 190
170   IF ((DIN-DOUT).GE.1.0) GO TO 180
      DELTA=1.0
180   TCOST=ACOST/DELTA
190   RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE RANK (TS1,TC1,TSS1,NSEQ,SEQ1,TV1)
      INTEGER*2 TV1(17000),SEQ1(17000)
      DIMENSION TS1(17000), TC1(17000),TSS1(17000)
      N2=NSEQ
      M1=N2
10    M1=INT(M1/2.)
      IF (M1.EQ.0) GO TO 50
      N1=N2-M1
      J=1
20    I=J
30    L1=I+M1
      IF (TC1(I).LE.TC1(L1)) GO TO 40
      A1=TC1(I)
      B1=TS1(I)
      C1=TSS1(I)
      A2=SEQ1(I)
      B2=TV1(I)
      TC1(I)=TC1(L1)
      TS1(I)=TS1(L1)
      TSS1(I)=TSS1(L1)
      SEQ1(I)=SEQ1(L1)
      TV1(I)=TV1(L1)
      TC1(L1)=A1
      TS1(L1)=B1
      TSS1(L1)=C1
      SEQ1(L1)=A2
      TV1(L1)=B2
      I=I-M1
      IF (I.GE.1) GO TO 30
40    J=J+1
      IF (J.LE.N1) GO TO 20
      GO TO 10
50    RETURN
      END
      SUBROUTINE SEARCH (LL,N0,CREQD,SREQD,SEQ,TV,TC,TSS,TS,IARRAY,TCMIN
     1,TSMAX,DIN,X)
      INTEGER T,S,S1,S2
      INTEGER*2 TV(20,300),SEQ(20,300)
      DIMENSION TC(20,1500), TS(20,1500), IARRAY(20), X(11,4,5)
     +,TSS(20,1500)
      PLACE=SREQD
      DO 10 I=1,N0
      TCTOT=TC(LL,I)*DIN*TSS(LL,I)
      TC(LL,I)=TCTOT
10    CONTINUE
      DTCMIN=TC(LL,N0)
```

```
      DTSMAX=TS(LL,NO)
20    IF (CREQD) 30,30,40
30    IF (SREQD) 160,160,60
40    K=NO
50    IF (TC(LL,K)-CREQD) 80,80,90
60    K=1
70    IF (TS(LL,K)-SREQD) 100,80,80
80    S1=SEQ(LL,K)
      T=TV(LL,K)
      IARRAY(LL)=T
      TCMIN=TC(LL,K)
      TSMAX=TS(LL,K)
      K=1
      GO TO 110
90    K=K-1
      IF (K) 140,140,50
100   K=K+1
      IF (K-NO) 70,70,140
110   I=LL-1
120   IF (I-1) 150,150,130
130   S=SEQ(I,S1)
      T=TV(I,S1)
      S2=S1
      S1=S
      IARRAY(I)=T
      I=I-1
      GO TO 120
140   WRITE (6,180)
      SREQD=TS(LL,NO)
      GO TO 20
150   IARRAY(1)=S
      GO TO 170
160   WRITE (6,200)
      STOP
       DEBUG SUBCHK
170   CONTINUE
      SREQD=PLACE
      RETURN
C
180   FORMAT (/1X,'REQUIREMENT CANNOT BE MET'/1X)
200   FORMAT (/1X,'REQUIREMENT CAN BE MET WITHOUT TEST SCREENS')
      END
      SUBROUTINE SSPROB (K1,K2,K3,K4,I1,I2,P,NCYC,CT,A1,B1,ITV,HOURS,PHR
     1,TIME,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,AMIN22,AMAX
     223,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAX41,AMIN41,
     3AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52)
      DIMENSION P(11,4,5), CT(5,5), TIME(3,5)
      GO TO (10,70,160,220,280), I2
10    CONTINUE
C  TEST ONE:  CONSTANT TEMPERATURE(CT)
      RR=((AMAX11-AMIN11)*K1+AMIN11*ITV-AMAX11)/(ITV-1.)
      RR=ABS(RR-25.)
      TT=((AMAX12-AMIN12)*K2+AMIN12*ITV-AMAX12)/(ITV-1.)
      HOURS=TT
      DT=ALOG(EXP(1.)+1.)
```

```
      RNCY=1.0                                                          SSPR 140
      PFT=.85*(1.0-EXP(-0.0023*RR**.6*TT**.5*RNCY*DT**2.7))             SSPR 150
      SS=1.0-PFT                                                        SSPR 160
      TIME(I1,I2)=HOURS                                                 SSPR 170
      IF (B1) 20,20,340                                                 SSPR 180
20    GO TO (30,40,50,60), I1                                           SSPR 190
30    CT(1,I2)=(0.15)*HOURS*CPHR                                        SSPR 200
      GO TO 350                                                         SSPR 210
40    CT(2,I2)=(0.15)*HOURS*CPHR                                        SSPR 220
      GO TO 350                                                         SSPR 230
50    CT(3,I2)=HOURS*CPHR                                               SSPR 240
      GO TO 350                                                         SSPR 250
60    CT(4,I2)=HOURS*CPHR                                               SSPR 260
      GO TO 350                                                         SSPR 270
70    CONTINUE                                                          SSPR 280
C  TEST TWO:  CYCLED TEMPERATURE(CYT)                                   SSPR 290
      RR=ABS(AMAX21-AMAX22)                                             SSPR 300
      DT1=((AMAX23-AMIN23)*K3+AMIN23*ITV-AMAX23)/(ITV-1.)               SSPR 310
      DT=ALOG(EXP(1.)+DT1)**2.7                                         SSPR 320
      RNCY=((AMAX24-AMIN24)*K4+AMIN24*ITV-AMAX24)/(ITV-1.)              SSPR 330
      TT=1.                                                             SSPR 340
      PFDT=.85*(1.-EXP(-.0023*RR**.6*TT*RNCY**.5*DT))                   SSPR 350
      SS=1.0-PFDT                                                       SSPR 360
      IF ((AMAX23-AMIN23)*K3+AMIN23*ITV-AMAX23) 90,90,80                SSPR 370
80    HOURS=RNCY*(4./DT+(2.*RR)/(DT*60.))                               SSPR 380
      TIME(I1,I2)=HOURS                                                 SSPR 390
      GO TO 100                                                         SSPR 400
90    HOURS=0                                                           SSPR 410
      TIME(I1,I2)=HOURS                                                 SSPR 420
100   IF (B1) 110,110,340                                               SSPR 430
110   GO TO (120,130,140,150), I1                                       SSPR 440
120   CT(1,I2)=(0.15)*HOURS*CPHR                                        SSPR 450
      GO TO 350                                                         SSPR 460
130   CT(2,I2)=(0.15)*HOURS*CPHR                                        SSPR 470
      GO TO 350                                                         SSPR 480
140   CT(3,I2)=HOURS*CPHR                                               SSPR 490
      GO TO 350                                                         SSPR 500
150   CT(4,I2)=HOURS*CPHR                                               SSPR 510
      GO TO 350                                                         SSPR 520
160   CONTINUE                                                          SSPR 530
C  TEST THREE:  RANDOM VIBRATION(RVIB)                                  SSPR 540
      GG=((AMAX31-AMIN31)*K1+AMIN31*ITV-AMAX31)/(ITV-1.)                SSPR 550
      TT=((AMAX32-AMIN32)*K2+AMIN32*ITV-AMAX32)/(ITV-1.)                SSPR 560
      HOURS=TT/60.                                                      SSPR 570
      BB=.266*GG+1.402                                                  SSPR 580
      DD=.144*GG-.0862                                                  SSPR 590
      PFV=DD*(1.-EXP(-TT**.5/BB))                                       SSPR 600
      SS=1.0-PFV                                                        SSPR 610
      TIME(I1,I2)=HOURS                                                 SSPR 620
      IF (B1) 170,170,340                                               SSPR 630
170   GO TO (180,190,200,210), I1                                       SSPR 640
180   CT(1,I2)=(0.15)*HOURS                                             SSPR 650
      GO TO 350                                                         SSPR 660
190   CT(2,I2)=(0.15)*HOURS                                             SSPR 670
      GO TO 350                                                         SSPR 680
```

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200   CT(3,I2)=HOURS
      GO TO 350
210   CT(4,I2)=HOURS
      GO TO 350
220   CONTINUE
C  TEST FOUR: SINE-SWEEP VIBRATION(SSVIB)
      TT=((AMAX42-AMIN42)*K2+AMIN42*ITV-AMAX42)/(ITV-1.)
      HOURS=TT/60.
      GG=((AMAX41-AMIN41)*K1+AMIN4I*ITV-AMAX41)/(ITV-1.)
      BB=.0176*GG+7.097
      DD=.0635*GG+.1065
      PWR=DD*(1.-EXP(-TT**.8/BB))
      SS=1.-PWR
      TIME(I1,I2)=HOURS
C   CARD/MODULE LEVELS
      IF (B1, 230,230,340
230   GO TO (240,250,260,270), I1
240   CT(1,I2)=(0.15)*HOURS*CPHR
      GO TO 350
250   CT(2,I2)=(0.15)*HOURS*CPHR
      GO TO 350
C   EQUIPMENT/SYSTEM LEVELS
260   CT(3,I2)=HOURS*CPHR
      GO TO 350
270   CT(4,I2)=HOURS*CPHR
      GO TO 350
280   CONTINUE
C  TEST FIVE:  SINE-FIXED VIBRATION (SFVIB)
      TT=((AMAX52-AMIN52)*K2+AMIN52*ITV-AMAX52)/(ITV-1.)
      GG=((AMAX51-AMIN51)*K1+AMIN51*ITV-AMAX51)/(ITV-1.)
      HOURS=TT/60.
      BB=-.419*G+8.620
      DD=.0435*G+.324
      PWRR=DD*(1.-EXP(-TT**.2/BB))
      SS=1.-PWRR
      TIME(I1,I2)=HOURS
C   CARD/MODULE LEVELS
      IF (B1) 290,290,340
290   GO TO (300,310,320,330), I1
300   CT(1,I2)=(0.15)*HOURS*CPHR
      GO TO 350
310   CT(2,I2)=(0.15)*HOURS*CPHR
      GO TO 350
C   EQUIPMENT/SYSTEM LEVELS
320   CT(3,I2)=HOURS*CPHR
      GO TO 350
330   CT(4,I2)=HOURS*CPHR
      GO TO 350
340   CT(I1,I2)=B1*HOURS+A1
350   CONTINUE
      DO 360 I=1,NCYC
      P(I,I1,I2)=SS
360   IF (HOURS.EQ.0.0) P(I,I1,I2)=1.0
      RETURN
      END
```

```
      SUBROUTINE REPORT (M,NCYC,N,ISCR,POEF,DIM,ADEF,CPHR,P,F,R1,R2,CT,C
     1R1,CR2,IARRAY,A1,B1,ITV,TCMIN,TSMAX,NPARTS,XNOP,XLAMP1,XLAMP2,XLAM
     2C1,XLAMC2,X,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AMAX22,AMIN2
     32,AMAX23,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN32,AMAX41,A
     4MIN41,AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52)
      REAL LCOST(5)
      DIMENSION AMAX11(3), AMIN11(3), AMAX12(3), AMIN12(3), AMAX21(3), A
     1MIN21(3), AMAX22(3), AMIN22(3), AMAX23(3), AMIN23(3), AMAX24(3), A
     2MIN24(3), AMAX31(3), AMIN31(3), AMAX32(3), AMIN32(3), AMAX41(3), A
     3MIN41(3), AMAX42(3), AMIN42(3), AMAX51(3), AMIN51(3), AMAX52(3), A
     4MIN52(3)
      DIMENSION NP(5,5,5), N(5), P(11,4,5), F(11,4,5), ISCR(3),
     1R1(11,4,5), R2(11,4,5), CR1(5,5), CR2(5,5), CT(5,5), SCOST(5,5),
     2TEST(5), IR(5), IARRAY(20), ANP(5,5,5), ADEF(5), TIME(3,5),
     +X(11,4,5)
      REWIND 10
      DATA NP/125*1/
      DATA LCOST/5*0./
      DATA TEST/'CT  ','CYT ','RVIB','SSVB','SFVB'/
      DATA ANP/125*0./
      I=0
      DO 130 I1=1,M
      DO 130 I2=1,5
      READ (10,*) A1,B1
      I=I+1
      IR(1)=IARRAY(I)
      GO TO (10,80,10,10,10) I2
      NP(I1,I2,1)=IARRAY(I)
      GO TO 120
10    DO 40 K=2,3
      IR(K)=MOD(IR(K-1),ITV**(3-K))
      IF (IR(K-1)) 30,30,20
20    NP(I1,I2,4-K)=INT(FLOAT(IR(K-1))/(FLOAT(ITV))**(3-K)+.999999)
      GO TO 40
30    NP(I1,I2,4-K)=ITV
40    CONTINUE
      GO TO 120
   88 DO 70 K=2,4
      IR(K)=MOD(IR(K-1),ITV**(4-K))
      IF (IR(K-1)) 60,60,50
50    NP(I1,I2,5-K)=INT(FLOAT(IR(K-1))/(FLOAT(ITV))**(4-K)+.999999)
      GO TO 70
60    NP(I1,I2,5-K)=ITV
70    CONTINUE
      GO TO 120
80    DO 110 K=2,5
      IR(K)=MOD(IR(K-1),ITV**(5-K))
      IF (IR(K-1)) 100,100,90
90    NP(I1,I2,6-K)=INT(FLOAT(IR(K-1))/(FLOAT(ITV))**(5-K)+.999999)
      GO TO 110
100   NP(I1,I2,6-K)=ITV
110   CONTINUE
      GO TO 120
120   CALL SSPROB (NP(I1,I2,1),NP(I1,I2,2),NP(I1,I2,3),NP(I1,I2,4),I1,I2
     1,P,NCYC,CT,A1,B1,ITV,HOURS,CPHR,TIME,AMAX11(I1),AMIN11(I1),AMAX12(
```

```
     2I1),AMIN12(I1),AMAX21(I1),AMIN21(I1),AMAX22(I1),AMIN22(I1),AMAX23(
     3I1),AMIN23(I1),AMAX24(I1),AMIN24(I1),AMAX31(I1),AMIN31(I1),AMAX32(
     4I1),AMIN32(I1),AMAX41(I1),AMIN41(I1),AMAX42(I1),AMIN42(I1),AMAX51(
     5I1),AMIN51(I1),AMAX52(I1),AMIN52(I1))
 130  CONTINUE
      CALL SCREEN (NCYC,M,N,PDEF,DIN,ADEF,P,F,R1,R2,CT,CR1,CR2,S,SM,FCOS
     1T,I1,I2,SCOST,TCMIN,1.0,TIME,NPARTS,XNOP,XLAMP1,XLAMP2,XLAMC1,XLAM
     2C2,X)
      DO 140 I1=1,M
      DO 140 I2=1,5
 140  LCOST(I1)=LCOST(I1)+SCOST(I1,I2)
      IQ=0
      WRITE (6,260)
      DO 250 I1=1,M
      AMP(I1,4,1)=((AMAX41(I1)-AMIN41(I1))*NP(I1,4,1)+AMIN41(I1)*ITV-AMA
     1X41(I1))/(ITV-1.)
      AMP(I1,1,1)=((AMAX11(I1)-AMIN11(I1))*NP(I1,1,1)+AMIN11(I1)*ITV-AMA
     1X11(I1))/(ITV-1.)
      AMP(I1,1,2)=((AMAX12(I1)-AMIN12(I1))*NP(I1,1,2)+AMIN12(I1)*ITV-AMA
     1X12(I1))/(ITV-1.)
      AMP(I1,5,1)=((AMAX51(I1)-AMIN51(I1))*NP(I1,5,1)+AMIN51(I1)*ITV-AMA
     1X51(I1))/(ITV-1.)
      AMP(I1,5,2)=((AMAX52(I1)-AMIN52(I1))*NP(I1,5,2)+AMIN52(I1)*ITV-AMA
     1X52(I1))/(ITV-1.)
      AMP(I1,2,1)=((AMAX21(I1)-AMIN21(I1))*NP(I1,2,1)+AMIN21(I1)*ITV-AMA
     1X21(I1))/(ITV-1.)
      AMP(I1,2,2)=((AMAX22(I1)-AMIN22(I1))*NP(I1,2,2)+AMIN22(I1)*ITV-AMA
     1X22(I1))/(ITV-1.)
      AMP(I1,2,3)=((AMAX23(I1)-AMIN23(I1))*NP(I1,2,3)+AMIN23(I1)*ITV-AMA
     1X23(I1))/(ITV-1.)
      AMP(I1,2,4)=((AMAX24(I1)-AMIN24(I1))*NP(I1,2,4)+AMIN24(I1)*ITV-AMA
     1X24(I1))/(ITV-1.)
      AMP(I1,3,1)=((AMAX31(I1)-AMIN31(I1))*NP(I1,3,1)+AMIN31(I1)*ITV-AMA
     1X31(I1))/(ITV-1.)
      AMP(I1,3,2)=((AMAX32(I1)-AMIN32(I1))*NP(I1,3,2)+AMIN32(I1)*ITV-AMA
     1X32(I1))/(ITV-1.)
      AMP(I1,4,2)=((AMAX42(I1)-AMIN42(I1))*NP(I1,4,2)+AMIN42(I1)*ITV-AMA
     1X42(I1))/(ITV-1.)
      KTT=2
      IF (ISCR(I1).EQ.2) KTT=4
      WRITE (13,*) AMP(I1,ISCR(I1),KTT)
      DO 250 I2=1,5
      GO TO (150,160,170,180,190), I2
 150  IF (AMP(I1,1,2).EQ.0) GO TO 200
      GO TO 220
 160  IF (AMP(I1,2,3).EQ.0) GO TO 200
      GO TO 220
 170  IF (AMP(I1,3,2).EQ.0) GO TO 200
      GO TO 220
 180  IF (AMP(I1,4,1).EQ.0) GO TO 200
      GO TO 220
 190  IF (AMP(I1,5,1).EQ.0) GO TO 200
      GO TO 220
 200  DO 210 K=1,4
 210  AMP(I1,I2,K)=0.
```

```
220   IF (I1-IQ) 240,240,230
230   WRITE (6,270) I1,LCOST(I1)
240   IF (ISCR(I1).NE.I2) GO TO 250
      WRITE (6,280) I2,TEST(I2),(ANP(I1,I2,K),K=1,4),SCOST(I1,I2)
250   IQ=I1
      WRITE (6,290) FCOST
      DEBUG SUBCHK
      RETURN
C
260   FORMAT (1X//////////29X,'T E S T   D E S C R I P T I O N'/39X,'PAR
     1AMETER VALUE'/10X,'TEST SEQUENCE',5X,'TYPE',2X,'NO. 1',2X,'NO. 2',
     22X,'NO. 3',2X,'NO. 4',2X,'TOTAL COST','($)'/7X,66('_')//)
270   FORMAT (' ',8X,'LEVEL',2X,'NO. ',I2,39X,F12.0)
280   FORMAT (' ',12X,'TEST  NO. ',I2,3X,A4,1X,4F7.2,F12.0)
290   FORMAT (' ',7X,67('_')//' ',8X,'TOTAL',' COST',41X,'$',F12.0//' ',
     161X,12('_')/' ',61X,12('_'))
      END
      SUBROUTINE DATA (NCYC,M,PDEF,CREQD,E,ITV,N,ADEF,CPHR,P,F,R1,R2,CR1
     1,CR2,XMTBF,LEVEL,ITYP,AMAX11,AMIN11,AMAX12,AMIN12,AMAX21,AMIN21,AM
     2AX22,AMIN22,AMAX23,AMIN23,AMAX24,AMIN24,AMAX31,AMIN31,AMAX32,AMIN3
     32,AMAX41,AMIN41,AMAX42,AMIN42,AMAX51,AMIN51,AMAX52,AMIN52,NPARTS)
      DIMENSION N(5), ADEF(5), P(11,4,5), F(11,4,5), R1(11,4,5),
     1 CR1(5,5), CR2(5,5), AMAX11(3), AMIN11(3), AMAX12(3), AMIN12(3), A
     2MAX21(3), AMIN21(3), AMAX22(3), AMIN22(3), AMAX23(3), AMIN23(3), A
     3MAX24(3), AMIN24(3), AMAX31(3), AMIN31(3), AMAX32(3), AMIN32(3), A
     4MAX41(3), AMIN41(3), AMAX42(3), AMIN42(3), AMAX51(3), AMIN51(3), A
     5MAX52(3), AMIN52(3) [illegible](11,4,[illegible]
      READ (4,*) NCYC,M,NPARTS,CREQD,E,ITV,XMTBF,CPHR
      READ (4,*,END=10) PDEF
      IF (PDEF) 10,10,20
10    PDEF=0.001*NPARTS
      GO TO 30
20    PDEF=PDEF*NPARTS
30    DO 60 I=1,M
      READ (4,*,END=40) ADEF(I)
      IF (ADEF(I)) 40,40,50
40    ADEF(I)=.005*NPARTS
      GO TO 60
50    ADEF(I)=ADEF(I)*NPARTS
60    CONTINUE
      WRITE (6,470)
      READ (5,*) ITABLE
      IF (ITABLE.LT.1) GO TO 90
      WRITE (6,500)
      IF (CREQD.GE.9.E9) GO TO 70
      WRITE (6,520) NPARTS,M,PDEF,CREQD,XMTBF
      GO TO 80
70    WRITE (6,480) NPARTS,M,PDEF
80    WRITE (6,510)
      WRITE (6,530) (I,ADEF(I),I=1,M)
90    DO 140 I1=1,M
      DO 140 I2=1,5
      READ (11,*,END=100) P(1,I1,I2)
      IF (P(1,I1,I2)) 100,100,120
100   DO 110 I=1,NCYC
```

```
110   F(I,I1,I2)=1.0
      GO TO 140
120   DO 130 I=1,NCYC
130   F(I,I1,I2)=F(1,I1,I2)
140   CONTINUE
      DO 190 I1=1,M
      DO 190 I2=1,5
      READ (8,*,END=150) F(1,I1,I2)
      IF (F(1,I1,I2)) 150,150,170
150   DO 160 I=1,NCYC
      F(I,1,I2)=0.0
      F(I,2,I2)=0.0
      F(I,3,I2)=0.0
160   F(I,4,I2)=0.0
      GO TO 190
170   DO 180 I=1,NCYC
180   F(I,I1,I2)=F(1,I1,I2)
190   CONTINUE
      DO 290 I1=1,M
      DO 290 I2=1,5
      READ (9,*,END=200) R1(1,I1,I2),R2(1,I1,I2)
      IF (R1(1,I1,I2)) 200,200,220
200   DO 210 I=1,NCYC
210   R1(I,I1,I2)=0.5
      GO TO 240
220   DO 230 I=1,NCYC
230   R1(I,I1,I2)=R1(1,I1,I2)
240   IF (R2(1,I1,I2)) 250,250,270
250   DO 260 I=1,NCYC
260   R2(I,I1,K2)=0.5
      GO TO 290
270   DO 280 I=1,NCYC
280   R2(I,I1,I2)=R2(1,I1,I2)
290   CONTINUE
      DO 430 I1=1,M
      DO 430 I2=1,5
      READ (4,*,END=300) B2,B3
      IF (B2) 300,300,350
300   GO TO (310,320,330,340), I1
310   CR1(1,I2)=0.0
      GO TO 360
320   CR1(2,I2)=0.0
      GO TO 360
330   CR1(3,I2)=0.0
      GO TO 360
340   CR1(4,I2)=0.0
      GO TO 360
350   CR1(I1,I2)=B2
360   IF (B3) 370,370,420
370   GO TO (380,390,400,410), I1
380   CR2(1,I2)=45.
      GO TO 430
390   CR2(2,I2)=300.
      GO TO 430
400   CR2(3,I2)=990.
```

```
      GO TO 430
410   CR2(4,I2)=0.0
      GO TO 430
420   CR2(I1,I2)=B3
430   CONTINUE
      IF (ITABLE.LT.1) GO TO 440
      WRITE (6,540)
      WRITE (6,490) (J,CR2(J,1),J=1,M)
440   DO 450 I=1,NCYC
      DO 450 J=1,M
      NJ=N(J)
      DO 450 K=1,NJ
      F(I,J,K)=F(1,J,K)
      R1(I,J,K)=R1(1,J,K)
450   R2(I,J,K)=R2(1,J,K)
      DO 460 IZ=1,M
C  TEST ONE:  CONSTANT TEMPERATURE
      READ (12,*) AMAX11(IZ),AMIN11(IZ)
      READ (12,*) AMAX12(IZ),AMIN12(IZ)
C  TEST TWO:  CYCLED TEMPERATURE
      READ (12,*) AMAX21(IZ),AMIN21(IZ)
      READ (12,*) AMAX22(IZ),AMIN22(IZ)
      READ (12,*) AMAX23(IZ),AMIN23(IZ)
      READ (12,*) AMAX24(IZ),AMIN24(IZ)
C  TEST THREE: RANDOM  VIBRATION
      READ (12,*) AMAX31(IZ),AMIN31(IZ)
      READ (12,*) AMAX32(IZ),AMIN32(IZ)
C  TEST FOUR:  SINE-SWEEP VIBRATION
      READ (12,*) AMAX41(IZ),AMIN41(IZ)
      READ (12,*) AMAX42(IZ),AMIN42(IZ)
C  TEST FIVE:  SINE-FIXED VIBRATION
      READ (12,*) AMAX51(IZ),AMIN51(IZ)
      READ (12,*) AMAX52(IZ),AMIN52(IZ)
460   CONTINUE
      RETURN
C
470   FORMAT (5X//5X,'IF YOU WISH A TABLE OF INPUTS ENTER 1, IF NOT,',' 
     1ENTER ZERO:')
480   FORMAT (' ',5X,I7,5X,I1,4X,F13.0,12X,'NA',13X,'NA')
490   FORMAT (17X,'LEVEL',I3,30X,F10.0)
500   FORMAT (1X///////34X,' PROGRAM DATA'/' ',80('_')/' ',7X,'NPARTS',3
     1X,'LEVELS',3X,'(PDEF X NPARTS)',6X,'CREQD',10X,'MTBF'/' ',80('-')/
     2/)
510   FORMAT (1X////33X,'  ASSEMBLY DATA'/' ',80('_')/' ',8X,'ASSEMBLY L
     1EVEL',2X,' ',2X,'EXPECTED NUMBER OF ASSEMBLY DEFECTS'/' ',8X,14('_
     2'),5X,35('_')//)
520   FORMAT (' ',5X,I7,5X,I1,4X,F13.0,2X,F13.2,5X,2X,F13.0)
530   FORMAT (' ',11X,I2,27X,F9.0)
540   FORMAT (1X////35X,' REWORK ','COST '/' ',80('_')//)
      END
      SUBROUTINE MEAN (XN,XLAMB,XNP,T,OMSS,FALL)
      IF (OMSS.GT.0.999) GO TO 10
      IF (T.LE.1.E-9) GO TO 10
      A0=XN*XLAMB
      A1=XNP
```

```
      RK=-ALOG(OMSS)/(XLAMB*T)
      A2=RK*XLAMB
      FALL=A0*T+A1*(1.-EXP(-A2*T))
      GO TO 20
10    FALL=0.0
20    RETURN
      END
```

PROGRAM LISTING FOR ADAPT. FORT

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```
      DIMENSION ADEF(5), ISCR(3), TIME(3), TS(3), COME(3), ON(3), PFALL(
     13), WFALL(3), AFALL(3), APFALL(3), AWFALL(3), F(3), MARK(3), MARKP
     2W(3), EL(3), PBL(3), WBL(3), BU(3), PBU(3), WBU(3), TS1(3), AT(3),
     3 AMTBF(7,7), PREM(7), WREM(7)
      FLAG=0.0
      READ (2,*) ISCR,M,NPARTS,PDEF,ADEF
      READ (13,*) XNOP,XLAMP1,XLAMP2,XLAMC1,XLAMC2
      READ (13,*) TIME,AT
      READ (2,*) TS(1),TS(2),TS(3)
      DO 10 I=1,3
      TS(I)=1.-TS(I)
      TS1(I)=TS(I)
10    CONTINUE
      READ (2,*) COME(1),COME(2),COME(3)
      READ (2,*) ON(1),ON(2),ON(3),PLEFT
      WRITE (6,260)
      ON3=(ON(3)-PLEFT)
      DO 20 KK=1,7
      PREM(KK)=(AMAX1(0.,PLEFT-4.+FLOAT(KK)))
      DO 20 KL=1,7
      WREM(KL)=AMAX1(0.,ON3-4.+FLOAT(KL))
      AMTBF(KK,KL)=(XNOP-WREM(KL))*XLAMC1+(FLOAT(NPARTS)-PREM(KK))*XLAMP
     11+WREM(KL)*XLAMC2+PREM(KK)*XLAMP2
      AMTBF(KK,KL)=1./AMTBF(KK,KL)
20    CONTINUE
      WRITE (6,270) WREM
      DO 30 KK=1,7
30    WRITE (6,280) PREM(KK),(AMTBF(KK,KL),KL=1,7)
      WRITE (6,290)
      READ (5,*) INTER
      IF (INTER.GT.0) GO TO 40
      PER=.99
      GO TO 50
40    WRITE (6,300)
      READ (5,*) PER
50    WRITE (6,310)
      DO 60 K=1,3
      F(K)=COME(K)-ON(K)
60    CONTINUE
70    PFALL(1)=IFIX((PDEF*(COME(1)-ON(1)))/COME(1))
      WFALL(1)=COME(1)-ON(1)-PFALL(1)
      PFALL(2)=IFIX((PDEF-PFALL(1))*(COME(2)-ON(2))/COME(2))
      WFALL(2)=COME(2)-ON(2)-PFALL(2)
      PFALL(3)=IFIX((PDEF-PFALL(1)-PFALL(2))*(COME(3)-ON(3))/COME(3))
      WFALL(3)=COME(3)-ON(3)-PFALL(3)
      IF (FLAG.GT.0.0) PLEFT=PDEF-PFALL(1)-PFALL(2)-PFALL(3)
      WLEFT=ON(3)-PLEFT
      WRITE (6,320)
      WRITE (6,330)
      WRITE (6,320)
      WRITE (6,350)
      WRITE (6,360) NPARTS,ADEF(1),ADEF(2),ADEF(3),PLEFT
      WRITE (6,370)
      WRITE (6,380)
      RMTBF=(XNOP-WLEFT)*XLAMC1+(FLOAT(NPARTS)-PLEFT)*XLAMP1+WLEFT*XLAMC
```

```
     12+PLEFT*XLAMP2
      RHTBF=1./RHTBF
      WRITE (6,390) PDEF,TS(1),TS(2),TS(3),WLEFT
      WRITE (6,340)
      WRITE (6,400)
      WRITE (6,410) ON(1),ON(2),ON(3),RHTBF
      WRITE (6,340)
      WRITE (6,320)
      WRITE (6,420)
      WRITE (6,420)
      WRITE (6,430)
      WRITE (6,440)
      WRITE (6,460)
      WRITE (6,450)
      WRITE (6,470)
      WRITE (6,460)
      WRITE (6,480)
      DO 80 IJ=1,3
      CALL BOUND (F(IJ),BL(IJ),BU(IJ),PER)
      CALL BOUND (PFALL(IJ),PBL(IJ),PBU(IJ),PER)
      CALL BOUND (WFALL(IJ),WBL(IJ),WBU(IJ),PER)
80    CONTINUE
      WRITE (6,490) PFALL(1),WFALL(1),F(1),PFALL(2),WFALL(2),F(2),PFALL(
     13),WFALL(3),F(3)
      WRITE (6,460)
      WRITE (6,520)
      WRITE (6,510)
      WRITE (6,460)
      WRITE (6,490) PBU(1),WBU(1),BU(1),PBU(2),WBU(2),BU(2),PBU(3),WBU(3
     1),BU(3)
      WRITE (6,460)
      WRITE (6,500)
      WRITE (6,510)
      WRITE (6,460)
      WRITE (6,490) PBL(1),WBL(1),BL(1),PBL(2),WBL(2),BL(2),PBL(3),WBL(3
     1),BL(3)
      WRITE (6,460)
      WRITE (6,440)
      IF (FLAG.GT.0.0) GO TO 180
      GO TO 90
90    CALL INT (XNOP,NPARTS,PLEFT,ON(3),XLAMP1,XLAMP2,XLAMC1,XLAMC2)
      WRITE (6,530)
      READ (5,*) IADAPT
      IF (IADAPT.LT.1) GO TO 220
      WRITE (6,540)
      READ (5,*) IFALL
      IF (IFALL.GT.0) GO TO 120
      WRITE (6,550)
      READ (5,*) AFALL(1),AFALL(2),AFALL(3)
      ICUE=0
100   DO 110 I=1,3
      MARK(I)=0
      IF (AFALL(I).LT.BL(I)) MARK(I)=1
110   CONTINUE
      MARKT=MARK(1)+MARK(2)+MARK(3)
```

```
      IF ((MARKT.EQ.0).AND.(ICUE.GT.0)) GO TO 140
      IF (MARKT.LE.0) GO TO 240
      CALL NUFLOW (MARK,COME,ON,TS,AFALL,F,TIME,XLAMP1,NPARTS)
      FLAG=1.0
      WRITE (6,560)
      GO TO 70
120   WRITE (6,570)
      IFW=0
      DO 130 I=1,3
      WRITE (6,580) I
      READ (5,*) APFALL(I),AWFALL(I)
      AFALL(I)=APFALL(I)+AWFALL(I)
130   CONTINUE
      ICUE=1
      GO TO 100
140   DO 170 I=1,3
      IF (APFALL(I).GE.PBL(I)) GO TO 150
      PFALL(I)=APFALL(I)
      WFALL(I)=AWFALL(I)
      MARKPW(I)=1
150   IF (AWFALL(I).GE.WBL(I)) GO TO 160
      WFALL(I)=AWFALL(I)
      PFALL(I)=APFALL(I)
      MARKPW(I)=1
160   AFALL(I)=PFALL(I)+WFALL(I)
170   CONTINUE
      IPW=MARKPW(1)+MARKPW(2)+MARKPW(3)
      IF (IPW.EQ.0) GO TO 240
      CALL NUFLOW (MARKPW,COME,ON,TS,AFALL,F,TIME,XLAMP1,NPARTS)
      FLAG=1.0
      WRITE (6,560)
      GO TO 70
180   IF (IPW.LT.1) GO TO 200
      DO 190 J=1,3
190   MARK(J)=MARKPW(J)
200   CONTINUE
      DO 210 J=1,3
      IF (MARK(J).LT.1) GO TO 210
      CALL SOLVE (J,ISCR,TS,TS1,AT)
210   CONTINUE
220   WRITE (6,590)
      READ (5,*) IEQ
      IF (IEQ.LT.1) GO TO 230
      CALL EQUIV (IEQ)
230   WRITE (6,250)
      READ (5,*) ICUMF
      IF (ICUMF.LT.1) GO TO 240
      XNP=ON(2)+ADEF(3)
      CALL FTIME (NPARTS,XLAMP1,XNP,TS(3),TIME(3))
240   STOP
C
C
250   FORMAT (1X/5X,'IF YOU HAVE TIMES TO FAILURE FOR LEVEL III',' ENTER
     1 1,'/6X,'IF NOT, ENTER ZERO:')
260   FORMAT (1X///////20X,'INSTANTANEOUS MTBF FOR REMAINING'/23X,' FLAW
```

```
     1S AT END OF SCREENING'///28X,' WORKMANSHIP')
270   FORMAT (1X,'  PARTS |',7(4X,F5.0)/1X,72('-'))
280   FORMAT (1X,F7.0,1X,'|',7(4X,F5.0))
290   FORMAT (1X//////5X,'IF YOU WISH A .99 PROBABILITY INTERVAL, ENTER'
     1,' ZERO'/5X,'IF YOU WISH TO ENTER A SMALLER PROBABILITY (FOR',' A
     2NARROWER INTERVAL)'/5X,'ENTER ONE:')
300   FORMAT (5X,'ENTER PROBABILITY DESIRED:')
310   FORMAT (////////25X,'STRESS SCREENING FLOW DIAGRAM'//)
320   FORMAT (1X,5(12('-'),3X))
330   FORMAT (1X,'| INCOMING |',3X,'| LEVEL 1  |',3X,'| LEVEL 2  |',3X,'
     1| LEVEL 3  |',3X,'| OUTGOING |')
340   FORMAT (1X,5('|',10X,'|',3X))
350   FORMAT (1X,'|#PARTS:   |',3X,3('|ADEF= ',4X,'|',3X),'|DEF P REM:|'
     1)
360   FORMAT (1X,'|',I10,'|',3X,3('|',F10.0,'|',3X),'|',F10.0,'|')
370   FORMAT (1X,4('|',10X,'|-->'),'|',10X,'|')
380   FORMAT (1X,'|#DEFECTS: |',3X,3('|TS=       |',3X),'|','DEF W REM:|
     1')
390   FORMAT (1X,'|',F10.0,'|',3X,3('|',F10.3,'|',3X),'|',F10.0,'|')
400   FORMAT (1X,'|',10X,'|',3X,3('|DEF PASSED|',3X),'|MTBF:     |')
410   FORMAT (1X,'|',10X,'|',3X,4('|',F10.0,'|',3X))
420   FORMAT (21X,3('|',14X))
430   FORMAT (21X,3('V',14X))
440   FORMAT (15X,3(14('-'),1X))
450   FORMAT (15X,3('|  EXPECTED  |',1X))
460   FORMAT (15X,3('|',12X,'|',1X))
470   FORMAT (15X,3('|          FALLOUT:  |',1X))
480   FORMAT (15X,3('| PRT WKM TOT|',1X))
490   FORMAT (15X,3('|',3(F4.0),'|',1X))
500   FORMAT (15X,3('|LOWR BND FOR|',1X))
510   FORMAT (15X,3('|CSS FALLOUT:|',1X))
520   FORMAT (15X,3('|UPPR BND FOR|',1X))
530   FORMAT (1X////5X,'IF YOU HAVE FALLOUT NUMBERS ENTER 1, IF NOT',',
     1ENTER ZERO:')
540   FORMAT (5X,'IF YOU HAVE SEPARATE FALLOUT FOR PARTS AND ','WORKMANS
     1HIP ENTER ONE'/5X,'IF YOU HAVE TOTAL FALLOUT ONLY AT',' EACH LEVEL
     2, ENTER ZERO:')
550   FORMAT (5X,' ENTER THE THREE ACTUAL FALLOUT NUMBERS, IN ORDER, ','
     1BY LEVEL:')
560   FORMAT (1X/////24X,'STRESS SCREENING RESULTS:'///)
570   FORMAT (5X,'ENTER, IN ORDER, ACTUAL FALLOUT:'/5X,'DUE TO    (A)','
     1 PARTS    (B) WORKMANSHIP, AS PROMPTED:')
580   FORMAT (5X,'FOR LEVEL',I2,':')
590   FORMAT (1X/5X,'IF YOU WISH TO ANALYZE EQUIVALENT SCREENS ','ENTER
     1 ONE'/6X,'IF NOT, ENTER ZERO:')
      END
      SUBROUTINE BOUND (X,BL,BU,PER)
      DIMENSION B(2), PR(2)
      IF (X.LE.0.) GO TO 50
      PR(2)=(1.-PER)/2.
      PR(1)=PER+PR(2)
      X1=2*X
C
      DO 40 I=1,2
      B(I)=(((FLOAT(I-2)*2.58*SQRT(2.))+SQRT(2.*2.58**2+4*X1))/2)**2
```

```
10    IF (B(I).LT.0.5) GO TO 20                                          BOUN 100
      CALL MDCH (X1,B(I),P,IER)                                          BOUN 110
      P=P-PR(I)                                                          BOUN 120
      B1=B(I)+0.005                                                      BOUN 130
      CALL MDCH (X1,B1,P1,IER)                                           BOUN 140
      P1=P1-PR(I)                                                        BOUN 150
      BN=B(I)-(P*0.005)/(P1-P)                                           BOUN 160
      IF (ABS(BN-B(I)).LE.0.0005) GO TO 30                               BOUN 170
      B(I)=BN                                                            BOUN 180
      GO TO 10                                                           BOUN 190
20    B(I)=0.0                                                           BOUN 200
      GO TO 40                                                           BOUN 210
30    B(I)=BN                                                            BOUN 220
40    CONTINUE                                                           BOUN 230
      BL=FLOAT(IFIX((AMAX1(B(1),2.)-2.)/2.))                             BOUN 240
      IF (B(1).LE.2.4) BL=0.                                             BOUN 250
      BU=FLOAT(IFIX(B(2)/2.+0.9))                                        BOUN 260
      IF (BU.LE.0.) BU=0.                                                BOUN 270
      GO TO 60                                                           BOUN 280
50    BL=0.                                                              BOUN 290
      BU=0.                                                              BOUN 300
60    RETURN                                                             BOUN 310
      END                                                                BOUN 320
      SUBROUTINE MEAN (N,XLAMB,XNP,T,OMSS,FALL)                          MEAN  10
      IF (OMSS.GT.0.999) GO TO 10                                        MEAN  20
      A0=N*XLAMB                                                         MEAN  30
      A1=XNP                                                             MEAN  40
      RK=-ALOG(OMSS)/(XLAMB*T)                                           MEAN  50
      A2=RK*XLAMB                                                        MEAN  60
      FALL=A0*T+A1*(1.-EXP(-A2*T))                                       MEAN  70
      GO TO 20                                                           MEAN  80
10    FALL=0.0                                                           MEAN  90
20    RETURN                                                             MEAN 100
      END                                                                MEAN 110
      SUBROUTINE NUFLOW (MARK,COME,ON,TS,AFALL,F,TIME,XLAMB1,NPARTS)     NUFL  10
      DIMENSION MARK(3), COME(3), ON(3), TS(3), AFALL(3), F(3), TIME(3) NUFL  20
      DO 10 I=1,1                                                        NUFL  30
      IF (MARK(I).LT.1) GO TO 10                                         NUFL  40
      TS(I)=AFALL(I)/COME(I)                                             NUFL  50
10    CONTINUE                                                           NUFL  60
      IF (MARK(1).LE.0) GO TO 20                                         NUFL  70
      PLACE=COME(1)*(1.-TS(1))                                           NUFL  80
      COME(2)=COME(2)+(PLACE-ON(1))                                      NUFL  90
      ON(1)=PLACE                                                        NUFL 100
      F(1)=COME(1)-ON(1)                                                 NUFL 110
20    IF (MARK(2).LT.1) GO TO 30                                         NUFL 120
      TS(2)=AFALL(2)/COME(2)                                             NUFL 130
30    OMSS=1.-TS(2)                                                      NUFL 140
      CALL MEAN (NPARTS,XLAMB1,COME(2),TIME(2),OMSS,F(2))                NUFL 150
      PLACE=COME(2)-F(2)                                                 NUFL 160
      COME(3)=COME(3)+(PLACE-ON(2))                                      NUFL 170
      ON(2)=PLACE                                                        NUFL 180
      IF (MARK(3).LT.1) GO TO 40                                         NUFL 190
      TS(3)=AFALL(3)/COME(3)                                             NUFL 200
40    OMSS=1.-TS(3)                                                      NUFL 210
```

```
      CALL MEAN (NPARTS,XLAMB1,COME(3),TIME(3),OMSS,F(3))
      CM(3)=COME(3)-F(3)
      RETURN
      END
      SUBROUTINE SOLVE (J,ISCR,TS,TS1,AT)
      DIMENSION ISCR(3), TS(3), TS1(3), AT(3), PARAM(3,5,4)
      REWIND 12
      DO 10 IM=1,3
      DO 10 K=1,5
      DO 10 M=1,4
      IF ((K.NE.2).AND.(M.GT.2)) GO TO 10
      READ (12,*) PARAM(IM,K,M),PARAM(IM,K,M)
10    CONTINUE
      DO 20 N=1,3
      MM=2
      IF (ISCR(N).EQ.2) MM=4
      PARAM(J,ISCR(N),MM)=AT(N)
20    CONTINUE
      IT=0
      CALL F (J,C1,IT,PARAM,TS,TS1,ISCR,T1,TNEW)
      IT=1
      T1=AT(J)
      CALL F (J,C1,IT,PARAM,TS,TS1,ISCR,T1,TNEW)
      IG=ISCR(J)
      GO TO (30,40,50,50,50), IG
30    IF (TNEW.GT.240.) TNEW=240.
      WRITE (6,70) J,TNEW
      GO TO 60
40    IF (TNEW.GT.40.) TNEW=40.
      WRITE (6,80) J,TNEW
      GO TO 60
50    IF (TNEW.GT.60.) TNEW=60.
      WRITE (6,90) J,TNEW
60    CONTINUE
      RETURN
C
C
70    FORMAT (1X//5X,'INCREASE TIME ON LEVEL',I2,' TO ',F10.2,' HOURS.')
80    FORMAT (1X//5X,'INCREASE NUMBER OF CYCLES ON LEVEL',I2,' TO ',F10.
     12//)
90    FORMAT (1X//5X,'INCREASE TIME ON LEVEL',I2,' TO ',F10.2,' MINUTES'
     1//)
      END
      SUBROUTINE F (J,C1,IT,PARAM,TS,TS1,ISCR,T1,TNEW)
      DIMENSION PARAM(3,5,4), ISCR(3), TS(3), TS1(3)
      IG=ISCR(J)
      GO TO (10,50,80,80,80), IG
10    IF (IT.GT.0) GO TO 20
      TIME=PARAM(J,1,2)
      ST=TS(J)
      GO TO 30
20    TNEW=((COM(ISCR(J),PARAM(J,ISCR(J),1))*T1**.5)/C1)**2
      GO TO 40
30    R=ABS(25.-PARAM(J,1,1))
      DT=ALOG(EXP(1.)+1.)
```

```
      C1=(-ALOG(1.-ST/.85)/(R**.6*OT**2.7*TIME**.5))
40    RETURN
50    IF (IT.GT.0) GO TO 60
      NCY=PARAM(J,2,4)
      ST=TS(J)
      GO TO 70
60    THEN=((CON(ISCR(J),PARAM(J,ISCR(J),1))*T1**.5)/C1)**2
      RETURN
70    R=PARAM(J,2,1)-PARAM(J,2,2)
      OT=ALOG(EXP(1.)+PARAM(J,2,3))
      C1=(-ALOG(1.-ST/.85)/(R**.6*OT**2.7*NCY**.5))
      RETURN
80    T=PARAM(J,ISCR(J),2)
      ST=TS(J)
      IG=ISCR(J)
      GO TO (90,90,90,100,110), IG
90    D=.144*PARAM(J,3,1)-.0862
      E=0.5
      GO TO 120
100   D=.0635*PARAM(J,4,1)+.1065
      E=0.8
      GO TO 120
110   D=.0435*PARAM(J,5,1)+.324
      E=0.2
120   IF (IT.GT.0) GO TO 130
      C1=-ALOG(1.-ST/D)/T**E
      RETURN
130   THEN=((T1**E*CON(ISCR(J),PARAM(J,ISCR(J),1)))/C1)**(1./E)
      RETURN
      END
      FUNCTION CON (I,PARAM)
      CON=0.0923
      GO TO (40,40,10,20,30), I
10    CON=(.266*PARAM+1.402)**(-1)
      GO TO 40
20    CON=(.0176*PARAM+7.097)**(-1)
      GO TO 40
30    CON=(-.419*PARAM+8.620)**(-1)
40    RETURN
      END
      SUBROUTINE EQUIV (MEQ)
      DIMENSION P(5,3,2), ISCR(2)
10    WRITE (6,130)
      FLAG=0.
C
      WRITE (6,140)
      READ (5,*) ISCR(1)
      WRITE (6,150)
      READ (5,*) ISCR(2)
C
      DO 70 I=1,2
      GO TO (20,30), I
20    WRITE (6,160)
      M=ISCR(I)
      GO TO (40,50,60,60,60), M
```

```
30    WRITE (6,170)
      M=ISCR(I)
      GO TO (40,50,60,60,60), M
40    WRITE (6,180)
      READ (5,*) P(1,1,I),P(1,2,I)
      GO TO 70
50    WRITE (6,190)
      READ (5,*) P(2,1,I),P(2,2,I),P(2,3,I)
      GO TO 70
60    WRITE (6,200)
      READ (5,*) P(ISCR(I),1,I),P(ISCR(I),2,I)
70    CONTINUE
C
      K=1
      CALL SSF (ISCR(1),K,P,X,FLAG,GTS)
      WRITE (6,210) GTS
      K=2
      X1=1.
      J=0
      CALL SSF (ISCR(K),K,P,X,FLAG,GTS)
      IF (FLAG.GT.0.) GO TO 110
      MM=ISCR(2)
      GO TO (80,90,100,100,100), MM
80    WRITE (6,220) X
      GO TO 120
90    WRITE (6,230) X
      GO TO 120
100   WRITE (6,240) X
110   FLAG=0.
120   WRITE (6,250)
      READ (5,*) L
      IF (L.GT.0) GO TO 10
      RETURN
C
C
130   FORMAT (1X/1X,'FOLLOWING ARE THE SCREEN EQUATIONS AVAILABLE:'/1X,'
     11.  CONSTANT TEMPERATURE'/1X,'2.  TEMPERATURE CYCLING'/1X,'3.  RAN
     2DOM VIBRATION'/1X,'4.  SINE SWEEP VIBRATION'/1X,'5.',' SINE FIXED
     3 VIBRATION'///)
140   FORMAT (1X,'ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO GIVEN ',
     1'SCREEN:')
150   FORMAT (1X,'ENTER NUMBER FROM ABOVE LIST CORRESPONDING TO ','DESIR
     1ED SCREEN:')
160   FORMAT (1X/1X,'ENTER PARAMETERS FOR GIVEN SCREEN:')
170   FORMAT (1X/1X,'ENTER PARAMETERS FOR DESIRED SCREEN;'/2X,'ENTER ZER
     1O FOR PARAMETER TO BE FOUND:')
180   FORMAT (1X/1X,'ENTER ABSOLUTE VALUE OF DIFFERENCE BETWEEN',' TEMP
     1IN DEG C AND 25 DEG C'/2X,'AND TIME IN HOURS')
190   FORMAT (1X/1X,'ENTER RANGE IN DEG C'/2X,'TEMP RATE OF CHANGE IN DE
     1G C/MIN'/2X,'AND NUMBER OF CYCLES')
200   FORMAT (1X/1X,'ENTER G LEVEL AND TIME IN MINUTES')
210   FORMAT (1X/1X,'TEST STRENGTH FOR GIVEN SCREEN=',F7.4)
220   FORMAT (1X/1X,' PARAMETER IN DESIRED CONSTANT TEMP SCREEN=',F10.1)
230   FORMAT (1X//1X,'PARAMETER IN DESIRED TEMP CYCLING ','SCREEN=',F10.
     11)
```

```
240   FORMAT (1X//1X,'PARAMETER FOR DESIRED VIBRATION ','SCREEN=',F10.1)
250   FORMAT (1X/////1X,'IF YOU WISH ANOTHER EQUIVALENCY ENTER ONE,',' I
     1F NOT, ENTER ZERO:')
      END
      SUBROUTINE SSF (ICUE,K,P,X,FLAG,GTS)
      DIMENSION P(5,3,2)
      GO TO (10,50,90,90,90), ICUE
10    IF (K.EQ.1) GO TO 30
      IF (P(1,1,2).GT.0.0) GO TO 20
      X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+1.)**2.7*P(1,2,2)**.5))
      X=X**(5./3.)
      GO TO 40
20    X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+1.)**2.7*P(1,1,2)**.6))
      X=X**2.
      RETURN
30    R=P(1,1,K)
      T=P(1,2,K)
      GTS=.85*(1.-EXP(-.0023*R**.6*ALOG(EXP(1.)+1.)**2.7*T**.5))
40    RETURN
50    IF (K.EQ.1) GO TO 80
      IF (P(2,1,K).GT.0.0) GO TO 60
      X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+P(2,2,K))**2.7))
      X=(X/P(2,3,K)**.5)**(5./3.)
      RETURN
60    IF (P(2,2,K).GT.0.0) GO TO 70
      X=(ALOG(1.-GTS/.85)/(-.0023*P(2,1,K)**.6*P(2,3,K)**.5))**(1./2.7)
      X=EXP(X)-EXP(1.)
      RETURN
70    X=((ALOG(1.-GTS/.85))/(-.0023*ALOG(EXP(1.)+P(2,2,K))**2.7))
      X=(X/P(2,1,K)**.6)**2.
      RETURN
80    R=P(2,1,K)
      RMCY=P(2,3,K)
      DT=ALOG(EXP(1.)+P(2,2,K))
      GTS=.85*(1.-EXP(-.0023*R**.6*DT**2.7*RMCY**.5))
      RETURN
90    IF (K.EQ.1) GO TO 100
      IF (P(ICUE,2,K).GT.0.0) GO TO 190
100   T=P(ICUE,2,K)
      GO TO (110,110,110,120,130), ICUE
110   B=.256*P(ICUE,1,K)+1.402
      D=.144*P(ICUE,1,K)-.0362
      C=.5
      GO TO 140
120   B=.0176*P(ICUE,1,K)+7.097
      D=.0635*P(ICUE,1,K)+.1065
      C=.8
      GO TO 140
130   B=-.419*P(ICUE,1,K)+8.62
      D=.0633*P(ICUE,1,K)+.324
      C=.2
140   GO TO (180,150), K
150   IF (GTS.GT D) GO TO 160
      X=(-B*ALOG(1.-GTS/D))**(1./C)
      GO TO 170
```

```
160   WRITE (6,230)
      FLAG=1.
170   RETURN
180   GTS=D*(1.-EXP(-T**C/B))
      RETURN
190   X1=1.
      J=0
200   XN=X1-(SSF1(ICUE,1,P,X1)-GTS)/SSF1(ICUE,2,P,X1)
      J=J+1
      IF (J.GT.50) GO TO 220
      IF (ABS(XN-X1).LE.0.005) GO TO 210
      X1=XN
      IF (X1.LE.0.) X1=J
      GO TO 200
210   X=XN
      RETURN
220   WRITE (6,240)
      FLAG=1.
      RETURN
C     DEBUG INIT
C
C
230   FORMAT (1X,'SOLUTION NOT POSSIBLE FOR DESIRED G LEVEL.')
240   FORMAT (1X,'SOLUTION CANNOT BE FOUND BY INTERNAL METHOD.'/2X,'TRY
     1A GRID OF POSSIBLE SOLUTIONS.')
      END
      FUNCTION SSF1 (IDS,L,P,X1)
      DIMENSION P(5,3,2)
      GO TO (10,20,30,30,30), IDS
10    T=X1
      RETURN
20    RNCY=X1
      RETURN
30    T=P(IDS,2,2)
      GO TO (40,40,40,50,60), IDS
40    B=.266*X1+1.402
      BB=.266
      D=.144*X1-.0862
      DD=.144
      C=.5
      GO TO 70
50    B=.0176*X1+7.097
      BB=.0176
      D=.0635*X1+.1065
      DD=.0635
      C=.8
      GO TO 70
60    B=-.419*X1+8.620
      BB=-.419
      D=.0435*X1+.324
      DD=.0435
      C=.2
70    IF (L.LT.2) GO TO 80
      SSF1=BB-DD*EXP(-T**C/B)-D*((T**C/B**2)**BB*EXP(-T**C/B))
      RETURN
```

```
80    SSF1=D*(1.-EXP(-T**C/B))
      RETURN
      END
      SUBROUTINE INT (XNOP,NPARTS,PLEFT,TLEFT,XLAMP1,XLAMP2,XLAMC1,XLAMC
     12)
C
      WRITE (6,20)
      A0=(XNOP-TLEFT+PLEFT)*XLAMC1+(FLOAT(NPARTS)-PLEFT)*XLAMP1
      A1=TLEFT
      A2=(PLEFT*XLAMP2+(TLEFT-PLEFT)*XLAMC2)/TLEFT
      T=2000.
      DO 10 I=1,10
      E=A0*T+A1*(1.-EXP(-A2*T))
      XMTBF=T/E
      WRITE (6,30) T,XMTBF
      T=T+2000.
10    CONTINUE
      RETURN
C
C
20    FORMAT (1X///////29X,'INTERVAL MTBF'//27X,17('-')/29X,'TIME  |','
     1 MTBF'/27X,17('-'))
30    FORMAT (28X,F6.0,' |',F7.0)
      END
      SUBROUTINE FTIME (NPARTS,XLAMB,XNP,SS,TIME)
C      SUBPROGRAM TO FIT FAILURE DATA TO
C     M(T)=A0*T+A1(1-EXP(-A2*T))
C     USING IMSL ROUTINE ZXSSQ
C
      EXTERNAL AMEANV
      REAL*4 PARM(4),X(2),F(200),XJAC(200,2),XJTJ(3),WORK(413)
      REAL*4 T(200)
      COMMON ZSQ,A0
C
      XN=FLOAT(NPARTS)
      RK=-ALOG(1.-SS)/(TIME*XLAMB)
      WRITE (6,10)
      READ (5,*) M
      K=2*M+13
      CALL OPT (AMEANV,XN,XLAMB,XNP,RK,PARM,X,F,XJAC,XJTJ,WORK,T,M,K,TIM
     1E)
      RETURN
C
10    FORMAT (5X,'ENTER NUMBER OF FAILURES DURING FINAL SCREEN:')
      END
      SUBROUTINE OPT (AMEANV,XN,XLAMB,XNP,RK,PARM,X,F,XJAC,XJTJ,WORK,T,M
     1,K,TIME)
      DIMENSION PARM(4), X(2), F(M), XJAC(M,2), XJTJ(3), WORK(K), T(M)
      COMMON ZSQ,A0
      WRITE (6,20)
      DO 10 IJ=1,M
      READ (5,*) T(IJ)
      WRITE (17,*) T(IJ)
10    CONTINUE
      N=2
```

```
      IXJAC=M
      NSIG=4
      EPS=0.0
      DELTA=0.0
      MAXFN=500
      IOPT=1
      A0=XN*XLAMB
      X(1)=XNP
      X(2)=RK*XLAMB*1.E3
      CALL ZXSSQ (AMEANV,M,N,NSIG,EPS,DELTA,MAXFN,IOPT,PARM,X,SSQ,F,XJAC
     1,IXJAC,XJTJ,WORK,INFER,IER)
      X(2)=X(2)*1.E-3
      CSS=(1.-EXP(-X(2)*TIME))
      WRITE (6,30) X(1),CSS
      RETURN
C
20    FORMAT (5X,'ENTER FAILURE TIMES (HOURS), IN ORDER, AS PROMPTED:')
30    FORMAT (5X,'THE FAILURE TIMES INDICATE THAT THE ESTIMATED NUMBER'/
     15X,' OF DEFECTIVES ENTERING THE SCREEN IS  ',F10.0/5X,' AND THE ES
     2TIMATED SCREENING STRENGTH IS ',F5.3,'.')
      END
      SUBROUTINE AMEANV (X,M,N,F)
      REAL*8 XX(2),FF(200),TT(200)
      REAL*4 X(N),F(M),T(200)
      COMMON ZSQ,A0
      REWIND 17
      XX(1)=X(1)
      XX(2)=X(2)*1.E-3
      DO 30 I=1,M
      READ (17,*) T(I)
      TT(I)=T(I)
      IF (TT(I)*XX(2).GT.170.D0) GO TO 10
      IF (XX(2).LT.0.D0) WRITE (6,40)
      FF(I)=A0*TT(I)+XX(1)*(1.D0-DEXP(-XX(2)*TT(I)))-DFLOAT(I)
      GO TO 20
10    FF(I)=A0*TT(I)+XX(1)-DFLOAT(I)
20    F(I)=FF(I)
30    CONTINUE
      RETURN
C
40    FORMAT (1X,'NEGATIVE A2 ATTEMPTED--NEW EXPECTED VALUES MAY',' BE N
     1EEDED.')
      END
```

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